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# THE CANADIAN FISH CULTURIST

ISSUE THIRTY-EIGHT

OCTOBER • 1966

Published at Ottawa by  
THE DEPARTMENT OF FISHERIES OF CANADA







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ROGER DUHAMEL, F.R.S.C.  
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY  
OTTAWA, 1967

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Minister of Fisheries



# A Technique for the Enumeration of Chum Salmon Fry in the Fraser River, British Columbia\*

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## Abstract

Sampling equipment suitable for capturing seaward migrant Pacific salmon fry in the upper tidal reaches of the Fraser River in British Columbia has been designed and operated by the Department and the International Pacific Salmon Fisheries Commission during the 1961 to 1965 period. Behavioural characteristics of migrant chum salmon fry (*Oncorhynchus keta*) have been described, and indices of annual abundance have been calculated from the data obtained during the sampling programs.

## Introduction

During the spring of 1961 personnel of the Resource Development Branch of the Department of Fisheries of Canada and of the International Pacific Salmon Fisheries Commission initiated studies designed to determine the feasibility of assessing the annual abundance of chum and pink salmon fry (*Oncorhynchus keta* and *O. gorbuscha*, respectively) produced from the Fraser River system in British Columbia (Figure 1). The two organizations were involved in this study because, under the existing Convention between Canada and the United States, the International Pacific Salmon Fisheries Commission is responsible for the protection, preservation, and extension of the sockeye and pink salmon stocks indigenous to the Fraser River system. The initial studies conducted in 1961 were primarily experimental in nature, designed to develop equipment suitable for sampling at the particular site chosen, and the results were to serve as a basis upon which fry enumeration programs could be developed; on pink salmon fry by the International Pacific Salmon Fisheries Commission, and on chum salmon fry by the Department of Fisheries.

The results of the study conducted in 1961 indicated that an index of salmon fry production could be obtained at the site chosen, and as a result, extensive sampling programs have been conducted annually since that year; to enumerate pink salmon fry in 1962 and 1964, and chum salmon fry in 1962, 1963, 1964 and 1965.

The chum salmon segment of this fry enumeration study constitutes one part of a comprehensive investigation of the Fraser River chum salmon stocks which was initiated by the Department of Fisheries in 1959 to assess the present condition of those stocks. An analysis of the information available concerning the chum salmon stocks of the Johnstone Strait, Georgia Strait and Fraser River area indicated that

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\*Received for publication March, 1966

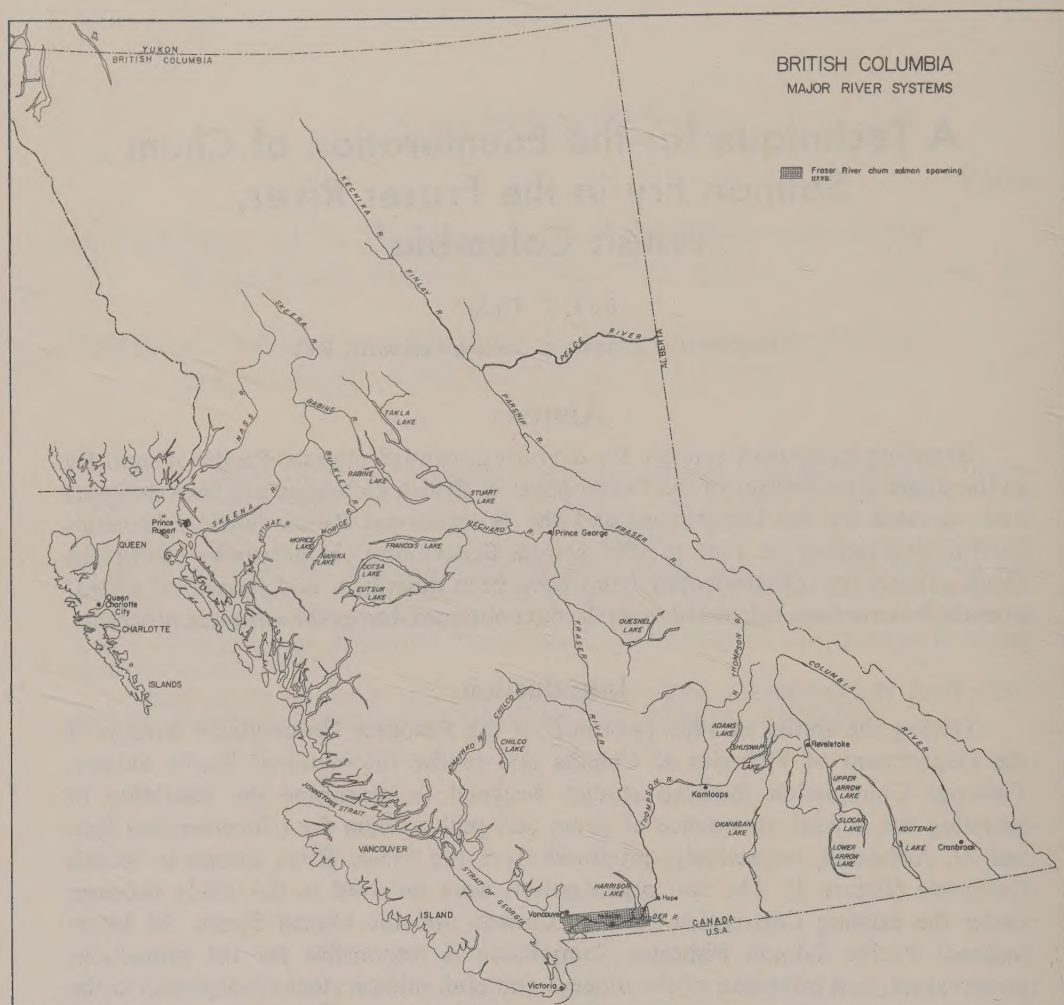


FIGURE 1. Location Map—British Columbia showing the Fraser River system.

the Fraser River stock has been the largest single population contributing to the commercial catch within the entire region<sup>1</sup>; a catch which prior to 1954 ranged between 900,000 and 3,200,000 chum salmon annually.<sup>2</sup> In 1955 the entire stock suffered a collapse, and in spite of ever-increasing restrictions which have been imposed upon the fishery, the stock has not demonstrated any indication of a return to its former levels of abundance. In 1960 a program was initiated to define the distribution and abundance of the chum salmon spawning populations in the Fraser River. The results of this study, which is presently continuing, indicated that chum salmon spawning is limited to the area bounded on the west by Mission City and on the east by the city of Hope (Figure 2). Major spawning populations have been located in the mainstem area of the Fraser River between the Agassiz-Rosedale



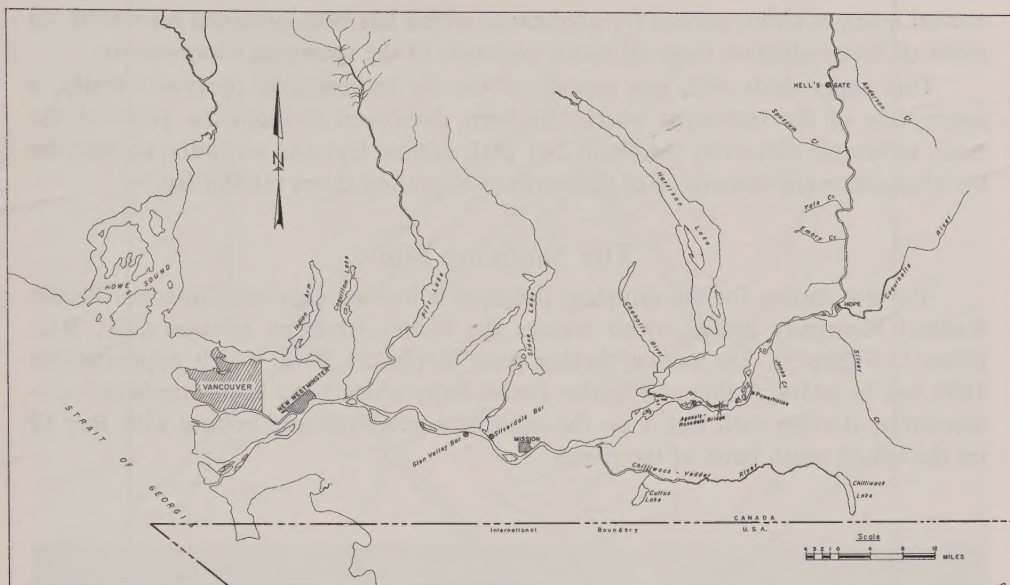


FIGURE 2. Location Map of the Fraser River system.

bridge and Hope City; in the two large tributary systems, the Chehalis-Harrison and Vedder-Chilliwack Rivers. In addition, minor populations utilize almost every small stream within the area.

In view of the fact that the mainstem spawning population represents a significant proportion of the total spawning escapement (Table I) it was considered that any assessment of fry production should, if possible, include fry produced by this segment of the escapement. For this reason the fry sampling site has been located near Mission City which is downstream from all major spawning areas, and the

Table I.

The annual escapement of chum salmon to the Fraser River system by number and percent of total for each major area during the period 1960 to 1964 inclusive.

| Year        | Harrison-Chehalis |         | Vedder-Chilliwack |         | Minor Tributaries |         | Mainstem |         | Total     |
|-------------|-------------------|---------|-------------------|---------|-------------------|---------|----------|---------|-----------|
|             | Number            | Percent | Number            | Percent | Number            | Percent | Number   | Percent |           |
| 1960.....   | 69,490            | 27.4    | 72,249            | 28.5    | 18,280            | 7.2     | 93,711   | 36.9    | 253,730   |
| 1961.....   | 38,861            | 23.7    | 46,593            | 28.4    | 22,239            | 13.5    | 56,462   | 34.4    | 164,155   |
| 1962.....   | 65,621            | 36.4    | 42,960            | 23.8    | 23,489            | 13.0    | 48,145   | 26.8    | 180,215   |
| 1963.....   | 88,739            | 41.4    | 56,940            | 26.6    | 46,704            | 21.8    | 21,842   | 10.2    | 214,225   |
| 1964.....   | 101,976           | 31.3    | 96,387            | 29.6    | 50,123            | 15.4    | 76,913   | 23.6    | 325,399   |
| Totals..... | 364,687           |         | 315,129           |         | 160,835           |         | 297,073  |         | 1,137,904 |
| Average.... | 72,937            | 32.1    | 63,025            | 27.7    | 32,167            | 14.1    | 59,414   | 26.1    | 227,543   |

annual index of chum salmon fry abundance which has been obtained represents an index of the production from all major segments of the spawning escapements.

This paper deals with two aspects of the fry enumeration program; firstly, a description of the technique which has been developed through the years of the study to sample effectively the chum and pink salmon fry; and secondly, to describe the abundance and behaviour of the seaward-migrating chum salmon fry.

### The Sampling Site

The site chosen for the sampling program is located near the Canadian Pacific Railway Company bridge which crosses the Fraser River at Mission City, B.C. (Plate I, Figure 3). The railway bridge piers divide the river, which approximates 1600 feet in width at this point, into twelve bays which have been numbered consecutively, starting with Bay 1 on the right or north bank and ending with Bay 12 on the left or south bank of the river.

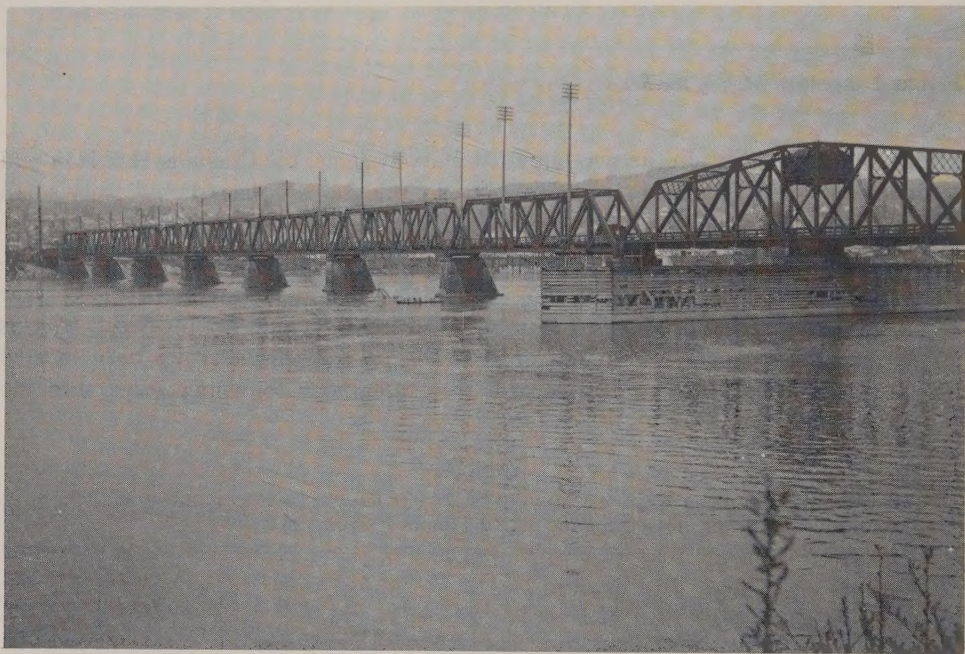


PLATE I. *The Canadian Pacific Railway Bridge over the Fraser River at Mission City, B.C.*

In the area upstream from the bridge, the river is dyked on both banks and is confined to a straight channel of relatively uniform width and depth for a distance of approximately two miles. Depth contours in the vicinity of the bridge are included in Figure 3.

The river at this location is subject to tidal influence which varies in intensity depending upon prevailing discharge conditions. During March and April, a period which encompasses a major segment of the chum salmon fry migration, water levels



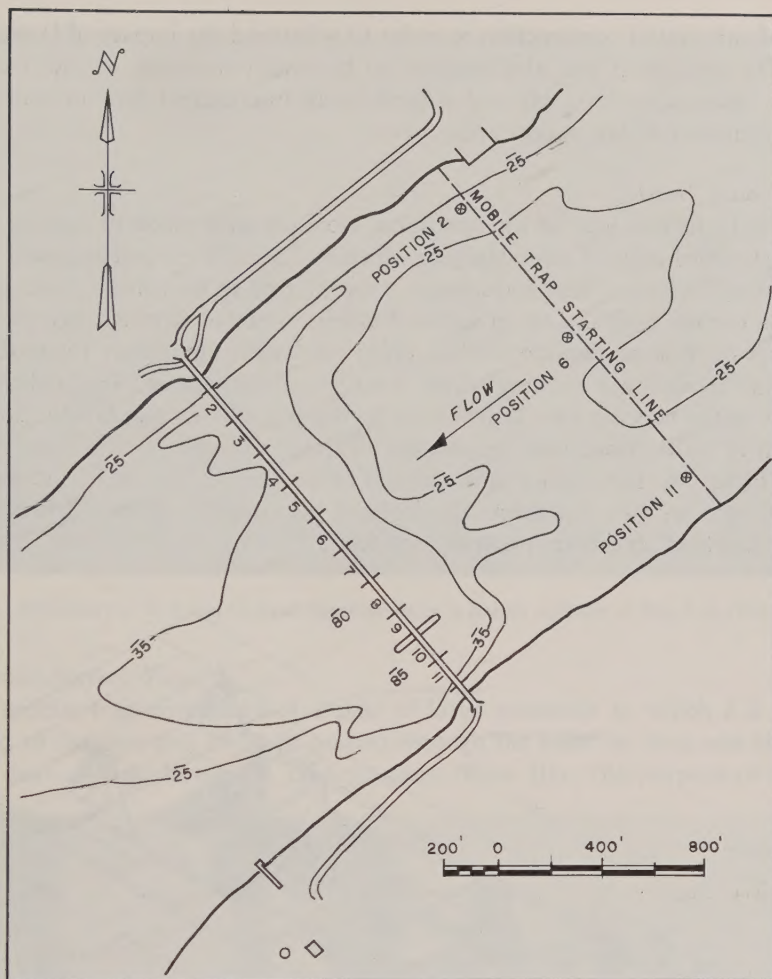


FIGURE 3. *Fraser River and bridge at Mission, B.C.*

are low, and during this period tidal inflow at times reduces the surface velocity in the centre of the river to one foot per second or less. At these times a slight upriver current prevails along both shores of the river. As the river levels increase during May, the effects of tidal inflow become less marked and the current, although perhaps reduced at periods of maximum high tides, continues to flow seaward at all times during the tidal cycle.

### The Development of Sampling Equipment

Seaward-migrating chum salmon fry appear at Mission during late February, and the migration period extends into early June. During this three-month period the Fraser River discharge demonstrates a progressive, although at times erratic, increase from winter low flow levels to discharges approaching spring freshet conditions. Equipment used to obtain samples of seaward-migrating salmon fry, therefore, had to be capable of withstanding extreme fluctuations in river level and velocity,

and be of substantial construction in order to withstand the impact of large floating debris. The equipment was also required to be readily movable, as the river at the sampling location is navigable and subject to an intermittent flow of traffic which consists primarily of log booms under tow.

#### (a) Stationary Traps

In 1961, the first year of the operation, attempts were made to capture migrant fry with standard units of sampling gear which had been developed and used successfully in smaller rivers. These traps, commonly referred to as inclined plane or scoop net traps, consist basically of an inclined screen mounted between two pontoons.<sup>3</sup> Two types of these traps were used in 1961; the larger, commonly referred to as a  $4 \times 4$ , has an entrance opening which measures 4 feet square. The inclined plane unit is mounted between two 24 feet long plywood pontoons and is adjustable as to the depth of water fished and the amount of water which is permitted to enter the livebox (Figure 4). The smaller unit, referred to as a  $2 \times 3$ , has an entrance opening three feet wide by two feet deep. The inclined plane unit is mounted between two plywood sheathed styrofoam pontoons ten feet long.

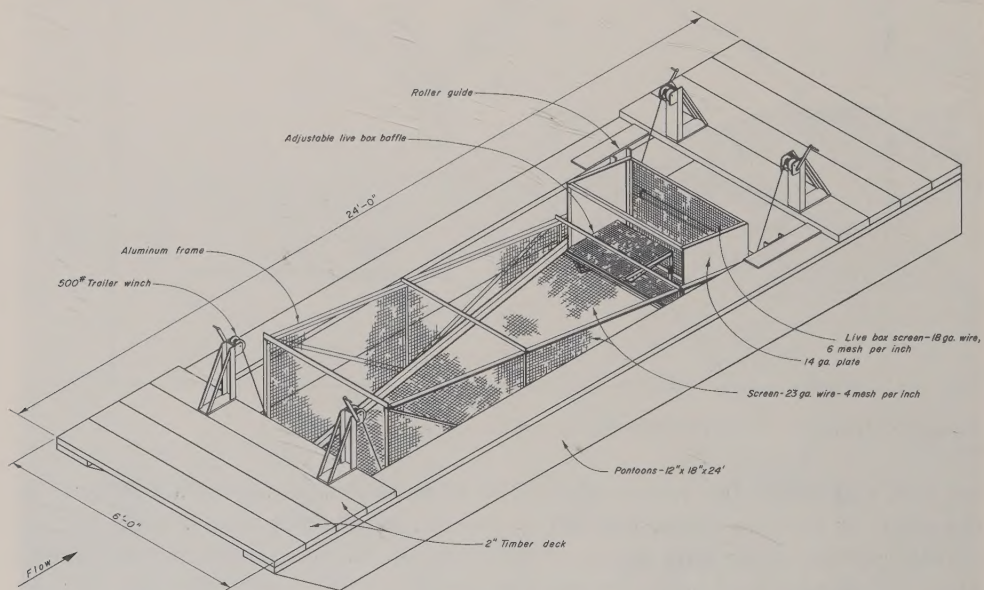


FIGURE 4. Standard  $4 \times 4$  inclined plane migrant trap.

Three of the  $2 \times 3$  units and one  $4 \times 4$  unit were moored to the bridge at certain bays in 1961. The positions of the traps during the sampling period were: Bay 2,  $2 \times 3$ ; Bay 8,  $4 \times 4$ ; Bay 10,  $2 \times 3$ . The third  $2 \times 3$  was fished in all other bays, with the position being altered daily.

Information concerning the vertical distribution of the migrant salmon was obtained by fishing two conical nets, one at the surface, and the other at intervals to depths of 12 feet, adjacent to the  $4 \times 4$  situated at the Bay 8 position (Plate II).





PLATE II. Stationary  $4 \times 4$  and vertical sampling units in fishing position at Bay 8 in 1961.

(b) *Mobile Surface Traps*

A mobile trap comprised of a pair of large pontoons to which a  $2 \times 3$  was attached so that the unit could be pushed through the water by boat was also fished several days a week during the 1961 program (Plate III). The purpose of sampling



PLATE III. Mobile  $2 \times 3$  and vertical sampling units used during 1961 season. Note stationary  $2 \times 3$  traps on dock.

with this unit was to explore the possibility of substituting a mobile unit for the stationary traps.

The results of the program conducted in 1961 indicated that mobile equipment was more satisfactory than the stationary units for obtaining samples of seaward-migrating fry for several reasons:<sup>4</sup>

(1) *River velocity:*

Stationary inclined plane units require a positive river velocity of at least two feet per second to ensure adequate capture and retention conditions for fry. During the early part of the fry migration the Fraser discharge is low and the tidal influence causes a continuous variation in velocity. At times the tidal effects were sufficient to swing the traps around so that the trap entrances faced downstream. During the latter part of the migration, when flows increased with the onset of spring freshet conditions, velocities increased to such an extent that the smaller two by three units in particular could not be fished.

The mobile trap, on the other hand, was operated at a constant speed which was maintained regardless of river level or tidal influence.

(2) *Catches of fry by the two gear types:*

Although the catch of chum salmon fry recorded from all traps was relatively small and extremely variable, the mobile trap catches, as presented in Table II, exceeded the catches of the stationary traps at all positions. The mobile trap, a  $2 \times 3$  unit, outfished even the larger  $4 \times 4$  unit which was operated as a stationary trap in Bay 8.

Table II.

A comparison of mobile two by three trap catches and stationary two by three trap catches recorded at Bays 2 and 10 with four by four catches recorded at Bay 8.

| Date        |         | Daily Catches          |                       |                        |                       |                        |                       |
|-------------|---------|------------------------|-----------------------|------------------------|-----------------------|------------------------|-----------------------|
|             |         | Bay 2                  |                       | Bay 8                  |                       | Bay 10                 |                       |
|             |         | Mobile<br>$2 \times 3$ | Fixed<br>$2 \times 3$ | Mobile<br>$2 \times 3$ | Fixed<br>$4 \times 4$ | Mobile<br>$2 \times 3$ | Fixed<br>$2 \times 3$ |
| April       | 2.....  | 36                     | 11                    | 24                     | 2                     | 20                     | 19                    |
|             | 4.....  | 8                      | 2                     | 0                      | 4                     | 12                     | 5                     |
|             | 5.....  | —                      | —                     | 12                     | 11                    | 16                     | 7                     |
|             | 8.....  | 198                    | 61                    | 93                     | 70                    | 21                     | 13                    |
|             | 15..... | 15                     | 26                    | 57                     | 64                    | 36                     | 25                    |
|             | 18..... | —                      | —                     | 27                     | 33                    | —                      | —                     |
|             | 20..... | 48                     | 62                    | 15                     | 31                    | 87                     | 52                    |
|             | 22..... | 129                    | 45                    | 72                     | 64                    | 54                     | 28                    |
|             | 25..... | 21                     | 23                    | 11                     | 19                    | 39                     | 8                     |
|             | 27..... | 38                     | 23                    | 24                     | 24                    | 12                     | 2                     |
|             | 29..... | 26                     | 14                    | 60                     | 43                    | 82                     | 49                    |
| May         | 2.....  | 68                     | 28                    | 140                    | 84                    | 168                    | 114                   |
|             | 4.....  | —                      | —                     | 48                     | 47                    | 54                     | 45                    |
|             | 9.....  | 8                      | 14                    | 0                      | 7                     | 8                      | 18                    |
|             | 11..... | —                      | —                     | 2                      | 0                     | —                      | —                     |
|             | 13..... | —                      | —                     | 6                      | 3                     | 6                      | 1                     |
| Totals..... |         | 595                    | 309                   | 591                    | 506                   | 615                    | 386                   |



(3) *Debris:*

During periods of increasing discharge, stationary traps required constant maintenance and repairs to damage caused by the impact of logs and other floating debris. The traps often fished at a reduced efficiency because of the debris load, and in some cases were torn from their moorings and lost. With the mobile trap, all debris of size which would cause damage was easily avoided, and constant maintenance was possible so that maximum fishing efficiency was maintained.

(4) *Weather conditions:*

Wave action caused by high winds affected both the mobile and stationary units to the degree that, occasionally, fishing was terminated or delayed for several hours. Severe winds also could affect the velocity of the mobile unit so that, depending upon wind direction, the unit either strained more or less water than would have been sampled had the velocity remained at the calibrated level.

(5) *Navigational responsibilities:*

Both mobile and stationary equipment must be marked according to Department of Transport regulations. Tug boats towing log booms represented a constant hazard both to personnel and to the stationary equipment. The danger of collision with river traffic was greatly lessened with the mobile unit.

(6) *Operational costs:*

The operation of a single mobile unit of equipment as opposed to four stationary traps reduced both the equipment and labour costs substantially, and at the same time provided a more effective sampling unit than did the stationary gear.

As a result of the problems associated with the operation of stationary equipment in 1961, a standard  $4 \times 4$  inclined plane trap was adapted for mobile operation in the 1962 season. This unit was secured alongside a 28-foot vessel and operated in the area upstream from the bridge at three locations in relation to Bays 2, 6, and 11 (see preceding Figure 3). Each sampling run was restricted to 15 minutes duration; each was conducted at a constant speed; and at the end of each run the unit was returned to a common starting line for the beginning of the next run.

The major disadvantage of this unit was that the trapping mechanism could not be lifted clear of the water at the end of a fishing run. This condition resulted in the trap being fished on the return run to the starting line and required that the livebox be emptied not only at the end of the actual fishing run but also at the end of each return run. The net result of this situation was that, as shown in Table III, the average number of 15-minute runs completed during an eight-hour standard shift in 1962 totalled 18.1; which meant that the unit was actually fishing just 56.6 percent of the total time available during each shift.

In 1963 the standard unit was modified as shown in Figure 5 so that the entire trapping mechanism could be lifted clear of the water at the end of each run. This modification eliminated the necessity for clearing the livebox at the end of each return run, and also permitted increased speed on the return run beyond levels which

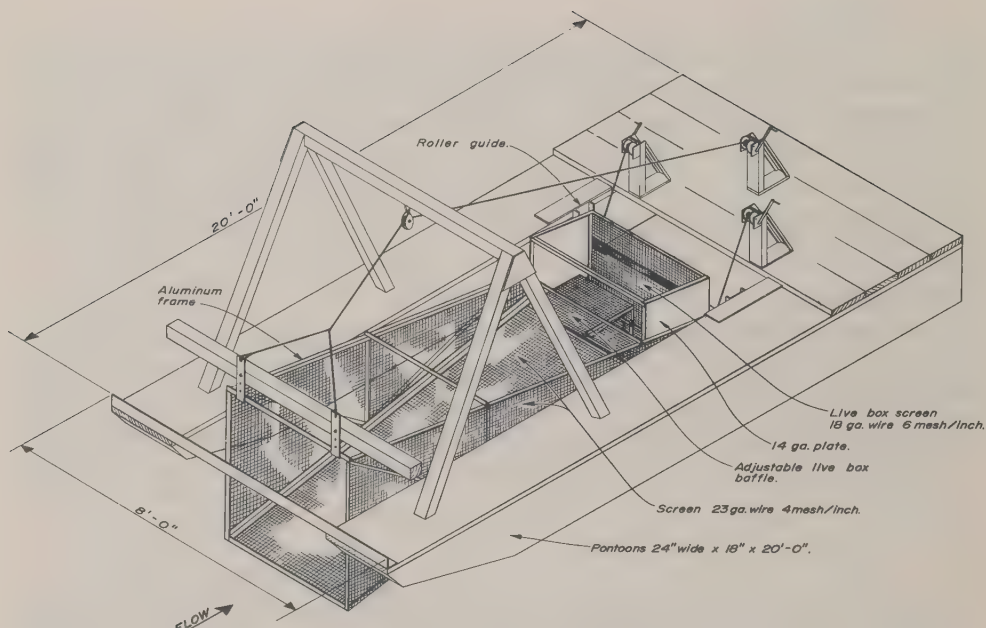


FIGURE 5. Isometric view of a standard  $4 \times 4$  inclined plane trap modified for use as a mobile unit.

were formerly acceptable. As shown in Table III, the average number of runs completed per eight-hour shift increased from 18 in 1962 to 22.5 in 1963. The efficiency of the unit, therefore, has been increased from a low of 56.6 percent in 1962 to a high of 75.0 per cent recorded in 1965.

Table III.

The average number of 15-minute runs completed per standard shift during each season and the per centage of actual fishing time completed per shift.

| Year      | Average Number of Runs per Shift | Maximum Number of Runs Possible in 8 hrs. | Percentage Efficiency |
|-----------|----------------------------------|-------------------------------------------|-----------------------|
| 1962..... | 18.1                             | 32                                        | 56.6                  |
| 1963..... | 22.5                             | 32                                        | 70.3                  |
| 1964..... | 22.6                             | 32                                        | 70.6                  |
| 1965..... | 24.0                             | 32                                        | 75.0                  |

Plates IV and V illustrate the modified mobile  $4 \times 4$  both in operating position during a sampling run and in lifted position for a returning run, respectively.

### (c) Mobile Vertical Trap

The depth of the Fraser River, as previously described, ranges between 20 and 25 feet at the sampling location. In order to assess the distribution and density of chum salmon fry migrating deeper than the 40-inch limit of the mobile  $4 \times 4$  trap,



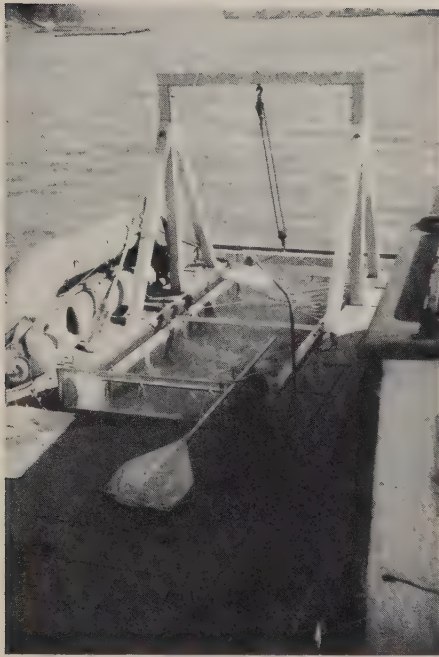


PLATE IV. *The modified mobile 4 × 4 trap in fishing position.*



PLATE V. *The modified mobile 4 × 4 trap in running position.*

an additional sampling unit was developed. This unit consists of two sock-type nets, one of which is fished continuously at the surface and the other at various depths within the limits of the sampling unit.

The surface net is mounted on a frame which is suspended between the pontoons at the front, or upstream end of the rig (Figure 6). This net, the entrance to which measures 36 inches wide and 40 inches deep, samples the same depth range that is fished by the mobile 4 × 4. The second unit, which is of the same size as the surface net, is set in a frame constructed of light channel iron which is suspended between the pontoons and extends to a maximum depth of 13'6". This frame acts as a guide rail for the net frame which, by means of a continuous line attached to a winch on deck may be positioned at any depth desired within the range of the guide track. In practice, this adjustable net is fished at depths of 40–80 inches, 80–120 inches, and 120–160 inches in alternate succession. The vertical sampling unit with both surface and deep net in operation is shown in Plate VI. The unit with both nets in raised position for the return run to the starting line is shown in Plate VII.

### The Sampling Technique

The basic program which evolved from the experimental approach of the 1961 season involved the capture of seaward migrant chum salmon fry by mobile equipment at three stations located in relation to Bays 2, 6, and 11 of the C.P.R. bridge near Mission City, B.C.

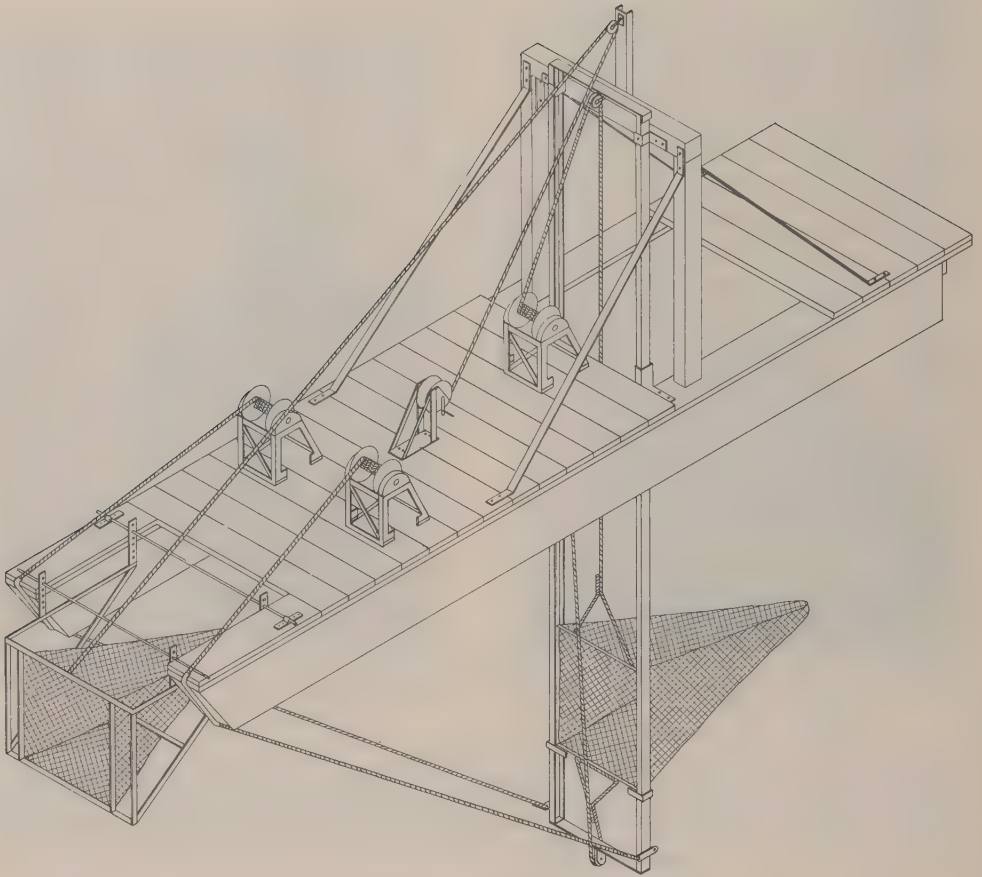


FIGURE 6. *Isometric view of the mobile vertical sampling unit shown with both nets in fishing position.*

In 1961 the starting position for each run of the mobile gear was initially located 1,000 feet downstream from the bridge. During periods of low discharge and/or flood tide conditions the sampling unit progressed upriver far enough during each run to encounter turbulence caused by the flow of water around the bridge piers. As a result of the danger involved to the personnel and equipment and the possible undesirable effects of the turbulence on catches made by the gear, the starting position was changed to a site located 2,000 feet upstream from the bridge, which eliminated the problems associated with sampling in the immediate vicinity of the bridge.

Operation of the mobile equipment was conducted at a constant speed from run to run and day to day. The velocity of water entering the mobile  $4 \times 4$  was selected in order to obtain adequate capture and retention conditions; to ensure adequate steerage way on the boat; and at the same time to cause no excessive mortality to fry within the livebox. On the basis of several trial runs a constant velocity of 2.6 feet per second was chosen as being the speed which would most closely satisfy the above conditions.





PLATE VI. *The modified mobile vertical sampling unit with nets in fishing position.*



PLATE VII. *The modified mobile vertical sampling unit with nets in running position.*

Initial tests were conducted prior to the first day of actual operation in all years to establish the engine tachometer readings necessary to maintain the desired velocity with only the mobile  $4 \times 4$  in operation, and again with both units in operation. The average seasonal velocities which corresponded to the two engine tachometer levels in each year are presented in Table IV.

In 1964 and 1965 velocity calibration tests were conducted weekly throughout each season, and the results of these tests are presented in Figure 7. The results of the tests conducted in 1964 indicated that a slight decrease in the velocity of the water entering the traps occurred as the season progressed. Very little difference existed between velocities measured during the standard shifts (i.e. when only the

Table IV.

Average seasonal velocities in feet per second measured at the entrance to the mobile four by four.

| Year      | Average velocity in feet per second |                    |
|-----------|-------------------------------------|--------------------|
|           | Engine RPM<br>800                   | Engine RPM<br>1100 |
| 1962..... | 2.58                                | 2.50               |
| 1963..... | 2.55                                | 2.50               |
| 1964..... | 2.66                                | 2.63               |
| 1965..... | 2.72                                | 2.58               |

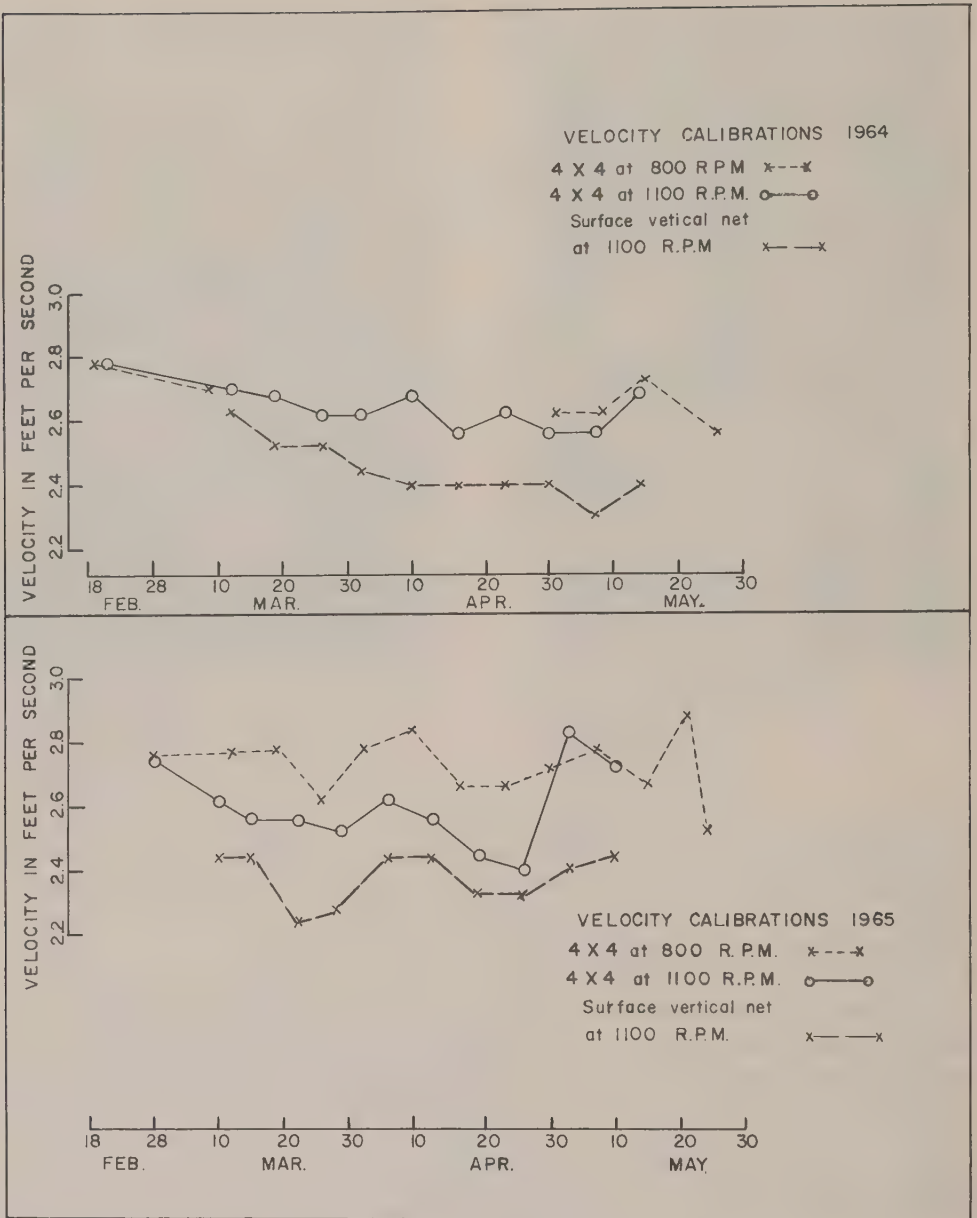


FIGURE 7. Results of velocity calibration tests conducted in 1964 and 1965.

4 X 4 was in operation) and the periods of twenty-four hour continuous fishing (i.e. when both units were in operation). Velocities recorded at the entrance to the surface net of the vertical sampling unit, however, were substantially lower than the levels recorded at the entrance to the 4 X 4 during the same tests. This difference was probably an indication that the nylon marquisette net of the vertical sampling unit provided more resistance to the passage of water than did the screening used on the inclined plane unit.



In 1965 calibrations were again conducted throughout the season, but results obtained were far more variable than those of 1964, as shown in Figure 7. Apart from the initial calibration tests which were conducted on February 28, velocities at the entrance to the  $4 \times 4$ , during periods when both units of gear were operating, were substantially lower than those recorded during periods when only the  $4 \times 4$  was in operation. This difference of approximately 0.2 feet per second remained relatively constant for all tests except the final two which were conducted during the first week of May. Velocities recorded at the entrance to the  $4 \times 4$  during these final two tests increased from a low of 2.4 feet per second to a high of 2.83 feet per second for no discernible reason. As recorded in 1964, velocities measured at the entrance to the surface net of the vertical sampling unit were lower than those measured at the entrance to the  $4 \times 4$ .

The results of the 1961 program indicated that the time of maximum migration of chum salmon occurred during the morning hours, and on this basis the period 0500 to 1300 hours was designated to be the standard fishing shift. Operation during the standard shift consisted of completing as many 15-minute runs at each of the three stations as possible during the eight-hour period. Single runs were made at each station in rotation starting at Bay 2, moving to Bay 6, then 11, back to 2, and so on throughout the shift. Each run was begun at the common starting line located 2,000 feet upstream from the bridge. Markers were established at 100 feet intervals along the dyke on the left bank of the river, and after each 15-minute run the total distance travelled upstream or downstream from the starting position was recorded.

In addition to the standard sampling shift which was fished six days a week, two additional eight-hour shifts were worked on both Mondays and Thursdays; the second shift from 1300 to 2100 hours; and the third shift from 2100 hours to 0500 hours the following morning. On the days of twenty-four hours continuous fishing, the mobile vertical sampler was operated in conjunction with the mobile  $4 \times 4$ . Catches obtained by shift and unit of gear were used to assess seasonal changes in the diel periodicity and vertical distribution of the fry.

In order to calculate daily indices of fry abundance from the 1962 data, it was assumed that the daily catches recorded in the mobile  $4 \times 4$  during the standard shift at each sampling position were representative of the average lateral distribution of fry within the one-third cross-section of the river that each sampling position represented. An attempt was made to assess the validity of this hypothesis in 1963, and two standard sampling shifts per week were allocated to this portion of the study. Each of these tests consisted of sampling at four positions in alternate succession within a 500-foot section of the width of the river for as many runs as possible during an eight-hour standard shift. One of the four test positions also corresponded to the standard sampling position: thus, to test lateral distribution within the one-third width of the river considered to be represented by catches recorded at the Bay 2 position, sampling was conducted at positions in relation to Bays 2, 3, 4, and 5; at Bay 6, by positions Bay 5, 6, 7, and 8; and at Bay 11, by positions Bay 8, 9, 10, and 11.

Tests designed to assess seasonal changes in the vertical distribution, diel periodicity, and lateral distribution of the fry have been incorporated with the standard sampling since 1962. The weekly schedule by which these tests are conducted is outlined in Table V.

Table V.

A typical sampling week designed to include tests for the seasonal changes in diel periodicity, vertical distribution, and lateral distribution of seaward migrant chum salmon fry.

| Day            | Gear Operating |                 | Shift Fished |           |           | Tests Conducted* |   |   |   |
|----------------|----------------|-----------------|--------------|-----------|-----------|------------------|---|---|---|
|                | 4 × 4          | Mobile Vertical | 0500-1300    | 1300-2100 | 2100-0500 | 1                | 2 | 3 | 4 |
| Monday.....    | X              | X               | X            | X         | X         | X                | X | X |   |
| Tuesday.....   | X              |                 | X            |           |           |                  |   |   | X |
| Wednesday..... | X              |                 | X            |           |           | X                |   |   |   |
| Thursday.....  | X              | X               | X            | X         | X         | X                | X | X |   |
| Friday.....    | X              |                 | X            |           |           |                  |   |   | X |
| Saturday.....  | X              |                 | X            |           |           | X                |   |   |   |
| Sunday.....    | No sampling    |                 |              |           |           |                  |   |   |   |

\*1 standard sampling at three basic locations

2 diel periodicity

3 vertical distribution

4 lateral distribution

## Distribution and Abundance of Chum Salmon Fry

### (a) Vertical Distribution

The mobile vertical sampling unit has been operated in conjunction with the mobile 4 × 4 twice weekly during the periods of 24-hour continuous fishing in all four study years. An example of typical catches recorded in the fixed surface and adjustable deep nets during the period of peak migration in all years is presented in Table VI. Data obtained in individual tests for each year are far too extensive to be presented in detail; catches recorded during April, the month of peak migration, however, were generally similar to or greater than those presented as an example in Table VI, while those recorded in March and May were generally smaller.

In order to calculate the proportion of fry which travelled in the surface 40 inches of water, average catches per run recorded at each depth level were calculated for each shift. These average catches per run were summed and the value calculated for each depth level was then expressed as a percentage of the total, as shown in the example presented in Table VI.

Standard shift catches expressed as the percentage of fry present in the surface 40 inches are plotted by sampling date in Figure 8. Seasonal changes in the proportion of chum salmon fry present in the surface 40 inches evidently occurred, particularly in 1962 and 1964 when a definite downward trend became evident as the season progressed. This phenomenon was not as noticeable during either 1963 or 1965; in fact, the 1963 data exhibited a trend toward an increased proportion of the fish being available within the surface 40 inches, while the 1965 data demonstrated a very slight downward trend as the season advanced.

Straight lines superimposed upon the data represent the calculated lines of best fit satisfying the equation  $y = mx + b$ ,<sup>5</sup> where  $x$  = sampling day and  $y$  = percentage present in the surface 40 inches on each test day. The calculated equations, coefficients



Table VI.

Catches of chum salmon fry recorded in the mobile vertical sampling unit April 9-10, 1964

| Run No.                    | Standard 0500-1300 Shift |        |         |          | Afternoon 1300-2100 Shift |        |         |          | Night 2100-0500 Shift |        |         |          |
|----------------------------|--------------------------|--------|---------|----------|---------------------------|--------|---------|----------|-----------------------|--------|---------|----------|
|                            | Surface<br>0-40"         | 40-80" | 80-120" | 120-160" | Surface<br>0-40"          | 40-80" | 80-120" | 120-160" | Surface<br>0-40"      | 40-80" | 80-120" | 120-160" |
| 1.....                     | 8                        | 0      | —       | —        | 16                        | —      | 12      | —        | 2                     | —      | —       | 0        |
| 2.....                     | 12                       | 3      | —       | —        | 7                         | —      | 2       | —        | 12                    | 2      | —       | —        |
| 3.....                     | 17                       | 3      | —       | —        | 14                        | —      | —       | 8        | 11                    | 1      | —       | —        |
| 4.....                     | 12                       | —      | 0       | —        | 8                         | —      | —       | 5        | 6                     | 0      | —       | —        |
| 5.....                     | 54                       | —      | 1       | —        | 12                        | —      | —       | 0        | 5                     | —      | 1       | —        |
| 6.....                     | 42                       | —      | 1       | —        | 26                        | 34     | —       | —        | 12                    | —      | 2       | —        |
| 7.....                     | 38                       | —      | —       | 0        | 20                        | 3      | —       | —        | 4                     | —      | 1       | —        |
| 8.....                     | 9                        | —      | —       | 0        | 6                         | 5      | —       | —        | 9                     | —      | —       | 2        |
| 9.....                     | 15                       | —      | —       | 0        | 25                        | —      | 6       | —        | 12                    | —      | —       | 1        |
| 10.....                    | 9                        | 6      | —       | —        | 16                        | —      | 7       | —        | 1                     | —      | —       | 0        |
| 11.....                    | 45                       | 21     | —       | —        | 1                         | —      | 2       | —        | 5                     | 0      | —       | —        |
| 12.....                    | 15                       | 4      | —       | —        | 11                        | —      | —       | 5        | 7                     | 2      | —       | —        |
| 13.....                    | 16                       | —      | —       | —        | 11                        | —      | —       | 1        | 4                     | 1      | —       | —        |
| 14.....                    | 28                       | —      | 17      | —        | 5                         | —      | —       | 0        | 9                     | —      | 0       | —        |
| 15.....                    | 21                       | —      | 10      | —        | 12                        | 7      | —       | —        | 17                    | —      | 2       | —        |
| 16.....                    | 15                       | —      | 1       | 6        | 14                        | 4      | —       | —        | 9                     | —      | 1       | —        |
| 17.....                    | 35                       | —      | —       | 1        | 4                         | 0      | —       | —        | 12                    | —      | —       | 3        |
| 18.....                    | 6                        | —      | —       | 0        | 23                        | —      | 4       | —        | 9                     | —      | —       | 2        |
| 19.....                    | 23                       | 20     | —       | —        | 9                         | —      | 0       | —        | 16                    | —      | —       | 0        |
| 20.....                    | 21                       | 13     | —       | —        | 3                         | —      | 2       | —        | 16                    | 2      | —       | —        |
| 21.....                    | 4                        | 10     | —       | —        | 1                         | —      | —       | 3        | 14                    | 5      | —       | —        |
| 22.....                    | 18                       | —      | 8       | —        | 9                         | —      | —       | 0        | —                     | —      | —       | —        |
| Totals.....                | 463                      | 70     | 38      | 7        | 253                       | 53     | 35      | 22       | 228                   | 13     | 7       | 8        |
| Average catch per run..... | 21                       | 7.8    | 5.4     | 1.2      | 11.5                      | 8.8    | 4.4     | 2.7      | 10.9                  | 1.6    | 1.2     | 1.1      |
| Per cent by depth.....     | 59.3                     | 22.0   | 15.3    | 3.4      | 42.0                      | 32.1   | 16.1    | 9.8      | 73.6                  | 10.8   | 8.2     | 7.4      |

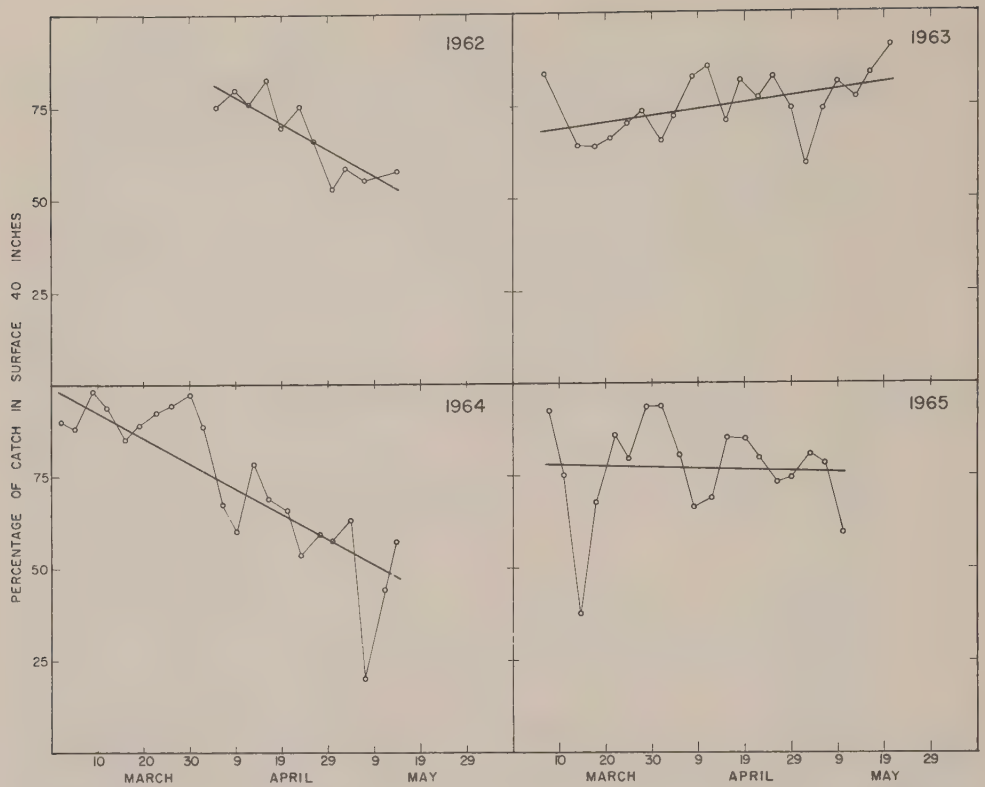


FIGURE 8. Seasonal changes in the proportion of chum salmon fry present in the surface to 40-inch depth during the standard shift (0500-1300).

of correlation, and levels of significance of the calculated "r" values are presented in Table VII. Significant correlations existed at a level of  $p = .05$  in 1962 and 1964, but not in 1963 and 1965.

Table VII.

The calculated linear regressions of changes in the proportion of chum salmon fry present in the surface levels during each shift throughout each season.

| Year      | Shift         | Linear Equation  | Coefficient of Correlation (r) | Significant Level $p = .05$ |
|-----------|---------------|------------------|--------------------------------|-----------------------------|
| 1962..... | 0500-1300 y = | $-.74x + 101.56$ | $-.83$                         | $\pm .62$                   |
|           | 1300-2100 y = | $.27x + 41.88$   | $+.15$                         | $\pm .62$                   |
|           | 2100-0500 y = | $-.86x + 95.95$  | $-.56$                         | $\pm .65$                   |
| 1963..... | 0500-1300 y = | $.16x + 67.92$   | $+.42$                         | $\pm .44$                   |
|           | 1300-2100 y = | $.45x + 49.04$   | $+.53$                         | $\pm .44$                   |
|           | 2100-0500 y = | $.19x + 57.50$   | $+.25$                         | $\pm .45$                   |
| 1964..... | 0500-1300 y = | $-.66x + 104.72$ | $-.80$                         | $\pm .42$                   |
|           | 1300-2100 y = | $-.53x + 85.96$  | $-.57$                         | $\pm .43$                   |
|           | 2100-0500 y = | $-.23x + 58.72$  | $-.29$                         | $\pm .46$                   |
| 1965..... | 0500-1300 y = | $-.03x + 77.44$  | $-.04$                         | $\pm .45$                   |
|           | 1300-2100 y = | $.27x + 59.91$   | $+.33$                         | $\pm .45$                   |
|           | 2100-0500 y = | $-.33x + 80.63$  | $-.42$                         | $\pm .48$                   |

The differences which existed in the data between the four study years cannot be explained on the basis of the information presently available. If change in season, per se, resulted in a gradual dispersal of the fry throughout the deeper sampling levels, then trends similar to those demonstrated in 1962 and 1964 should have occurred in 1963 and 1965 as well.

Changes in water levels throughout the season could have an effect on the vertical distribution of migrant fry. Maximum daily gauge readings recorded at the Mission bridge by the Waters Resources Division of the Department of Northern Affairs and National Resources have been plotted for each year in Figure 9. There is no suggestion that water levels in 1962 and in 1964 were similar in those years and at the same time substantially different from the 1963 and 1965 levels. The effect of increased water levels and associated changes in turbidity would not, therefore, appear to have been associated with the differences in vertical distribution which have occurred.

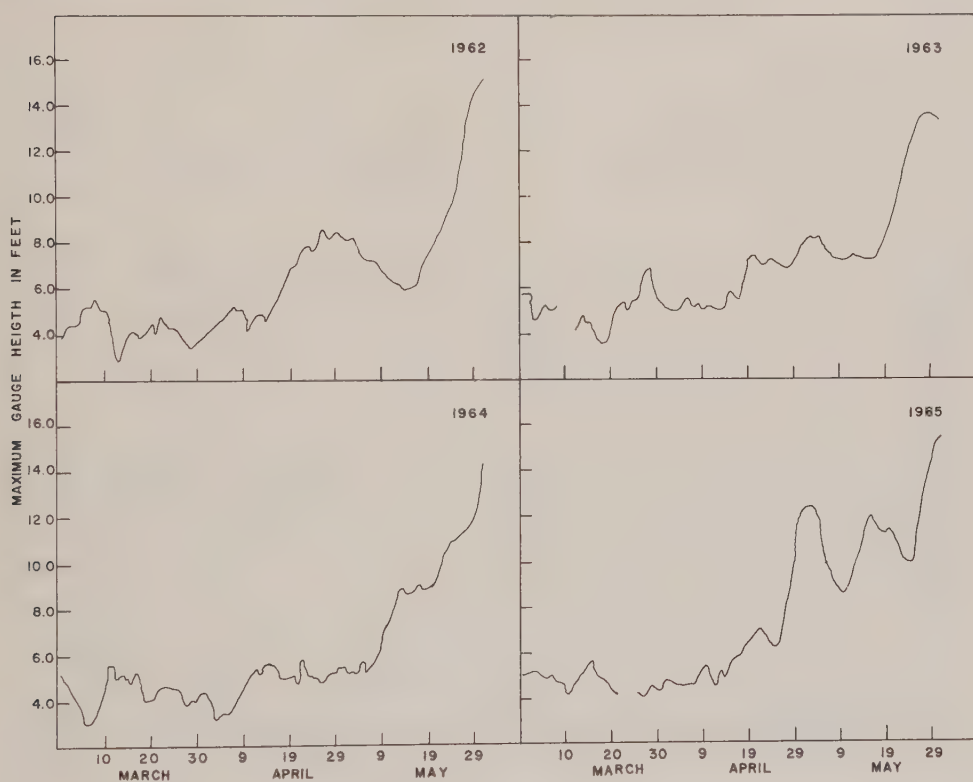


FIGURE 9. Maximum daily water levels recorded at Mission Bridge during the period March 1 to May 31 in the years 1962 to 1965 inclusive.

Pink salmon fry were present in 1962 and 1964, but were not present in 1963 or 1965. In that a smaller proportion of pink salmon fry was present in the surface levels\*, and as pink salmon fry were far more abundant than chum salmon fry, the

\*Vernon, E.—personal communication.



possibility must be considered that the distribution of the chum salmon fry was affected by the presence of the more abundant pinks. Data obtained from vertical distribution tests conducted during the afternoon (1300-2100) and night (2100-0500) shifts are presented graphically in Figure 10. In general, the trends established for these tests correspond to the trends described for the standard shift (0500-1300) tests, but as indicated by the data presented in Table VI are not as strong. The reason for the significant trends expressed by the vertical distribution data obtained during the standard sampling shifts in 1962 and 1964 cannot be defined on the basis of the information available; the possibility that the chum fry distribution is affected by the distribution of the more abundant pink salmon fry, however, cannot be totally dismissed.

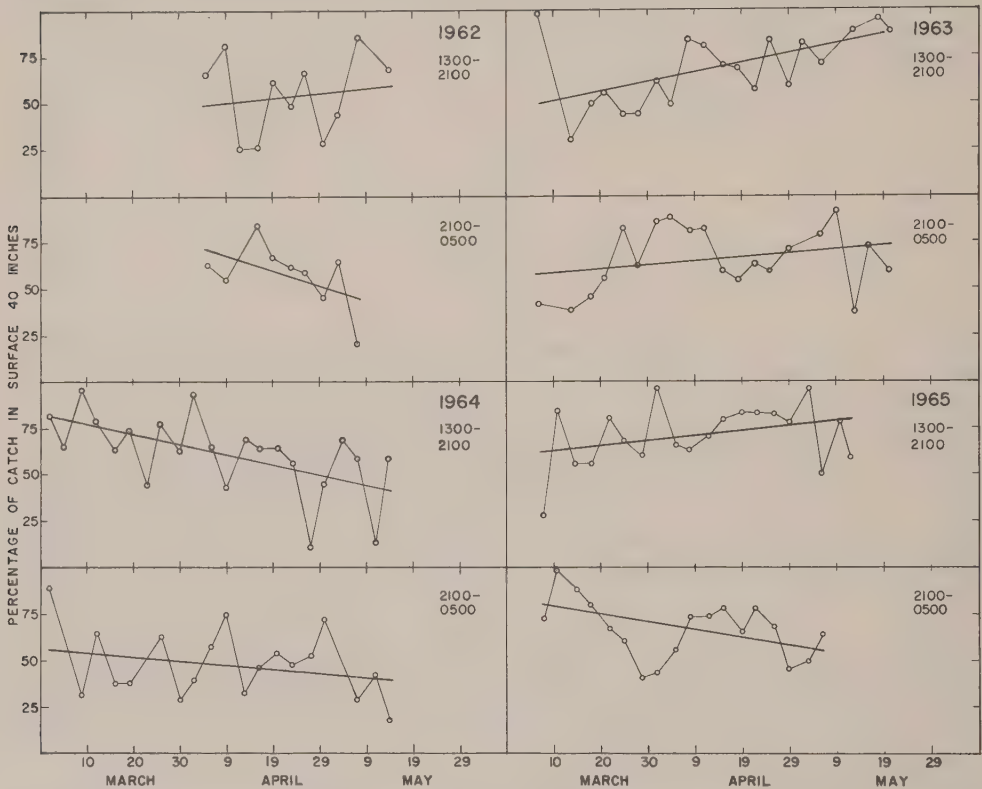


FIGURE 10. Seasonal changes in the proportion of chum salmon fry present in the surface to 40-inch depth during the afternoon (1300-2100) and night (2100-0500) shifts.

Although seasonal trends in the proportion of chum salmon fry present in the surface 40 inches of the river during the standard shift differed significantly from year to year, the average seasonal distribution computed from the results of all tests conducted during each season exhibited remarkable similarities (Figure 11). A comparison of the average distributions recorded during the standard shifts suggests that a relatively small proportion of the total migration was present at depths greater than those sampled.

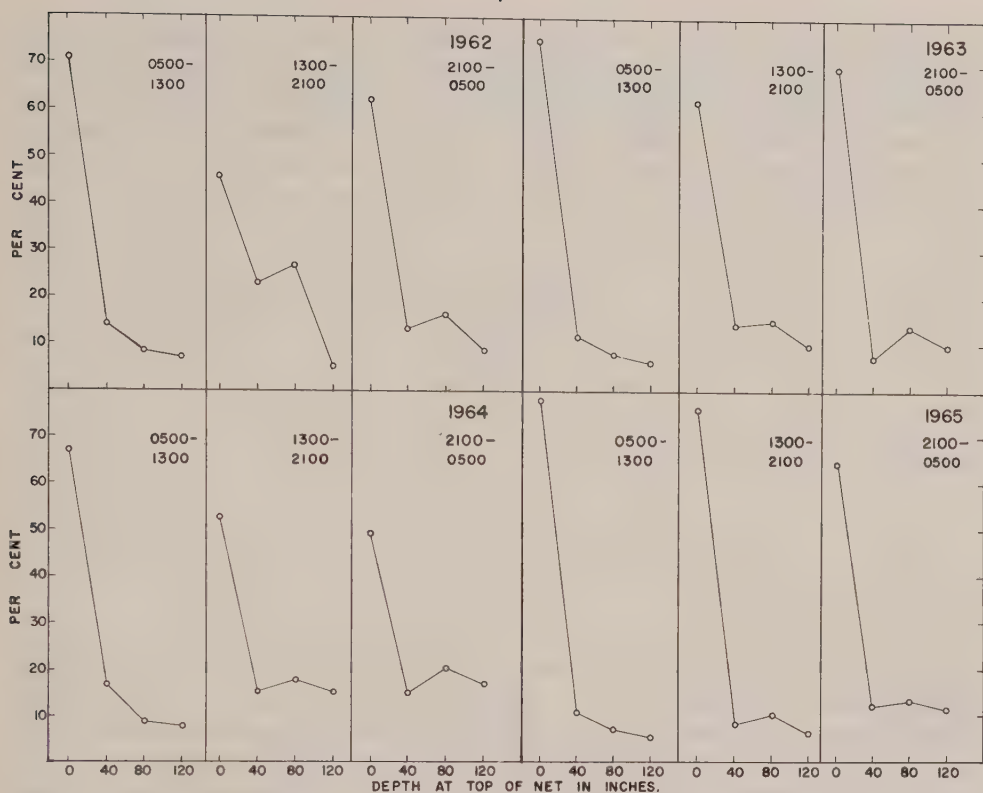


FIGURE 11. *The average seasonal vertical distribution of chum salmon fry recorded at each sampling depth for all shifts in the years 1962-1965 inclusive.*

The results presented in Figure 11 indicate for each year that the proportion of the fish present at the surface levels was substantially lower during both the afternoon and the night shifts. Rather than a displacement occurring primarily between the surface level and the next deeper level, however, the fry appeared to disperse fairly evenly throughout the three deep sampling levels. There is no reason to expect therefore, that the proportion of the fry present at depths beyond the limit of the sampling gear was not also increased during the afternoon and night shifts.

Although the river exceeds depths of 20 feet at the sampling site, assessment with the mobile gear was restricted to approximately 13 feet because of the presence of snags, particularly in the shore areas. During the 1964 season, the International Pacific Salmon Fisheries Commission designed and operated a fixed vertical sampling unit in an attempt to assess the total vertical distribution of pink salmon fry. This unit was operated during the same twenty-four hour periods that the mobile vertical unit was in operation and sampled the depths from 12 feet to the bottom of the river (27 feet at the stationary vertical sampling site). Effective fishing was accomplished primarily during the periods of ebbing tide, particularly during March and April when the river level was low and velocities were substantially affected by tidal flow. Increased periods of fishing were possible during May after the river had begun to rise.

Chum salmon fry were captured at all levels sampled, although catches were so small as indicated by the data presented in Table VIII, that trends were not evident on a day-to-day or shift-to-shift basis. The fact remains, however, that some chum salmon fry did travel at depths beyond the limit of the mobile vertical sampling unit, and the possibility exists that these fish represented a significant proportion of the total migration, particularly during the afternoon and night shifts.

Table VIII.

A summary of the chum salmon fry catches recorded in the fixed vertical sampling unit operated during the 1964 season.

| Fishing position | Total number of Fishing hours | Total catch of Chum fry | Average catch per hour | Per cent by position |
|------------------|-------------------------------|-------------------------|------------------------|----------------------|
| 12'.....         | 160                           | 118                     | .74                    | 34.2                 |
| 18'.....         | 146                           | 115                     | .79                    | 36.5                 |
| 20-27'.....      | 128                           | 81                      | .63                    | 29.3                 |

(b) *Diel Periodicity*

Observations recorded during the exploratory program conducted in 1961 indicated that the chum salmon fry migration was not confined to a specific period within a given day, although a peak concentration was generally recorded during the morning hours. In order to assess any seasonal changes that might occur in the time of this peak concentration, periods of twenty-four hour consecutive fishing were implemented twice weekly as previously described. The catches recorded in the mobile 4 × 4 sampling unit during these twice-weekly periods were used as the basis upon which to calculate seasonal changes in the peak of daily migration.

For the purposes of calculation, catches of the mobile inclined plane unit were totalled for each shift. These catches were adjusted, as described below to compensate for the differences in availability caused by the fluctuations which occurred in vertical distribution from shift to shift. As shown in the example presented in Table IX, the standard shift catch recorded in the mobile 4 × 4, which is designed to sample an area 48 inches wide by 40 inches deep, totalled 505.3 chum fry. In terms of the vertical distribution of fish, which was assessed during the same period, this catch

Table IX.

An example of calculations involved in the computation of the proportion of the chum salmon fry which migrated past the sampling site during each eight-hour shift of a 24-hour period, for April 13-14, 1964.

| Shift          | Unadjusted Data |                    | Vertical Distribution % in 0-40" | Adjusted Data |                    |
|----------------|-----------------|--------------------|----------------------------------|---------------|--------------------|
|                | Catch/Shift     | Per cent Per Shift |                                  | Catch/Shift   | Per cent Per Shift |
| 0500-1300..... | 505.3           | 36.1               | 77.5                             | 652.1         | 29.7               |
| 1300-2100..... | 752.6           | 53.7               | 68.6                             | 1097.1        | 50.0               |
| 2100-0500..... | 142.9           | 10.2               | 32.2                             | 443.8         | 20.3               |
| Totals.....    | 1400.8          | 100.0              |                                  | 2193.0        | 100.0              |



represented 77.5 per cent of the fish available within a column of water 48 inches wide and 13 feet 4 inches deep, which represents the total range of the vertical sampling unit. If 100 per cent of the chum salmon fry within this column had been available to the mobile  $4 \times 4$ , therefore, the catch recorded during the standard shift would have totalled  $\frac{100}{77.5} \times 505.3 = 652.1$ . Similar adjustments of catches recorded during the afternoon and night shifts were applied as shown in Table IX. The adjusted catches per shift were then summed, and each adjusted catch /shift was then expressed as a percentage of the total adjusted catch /24 hours.

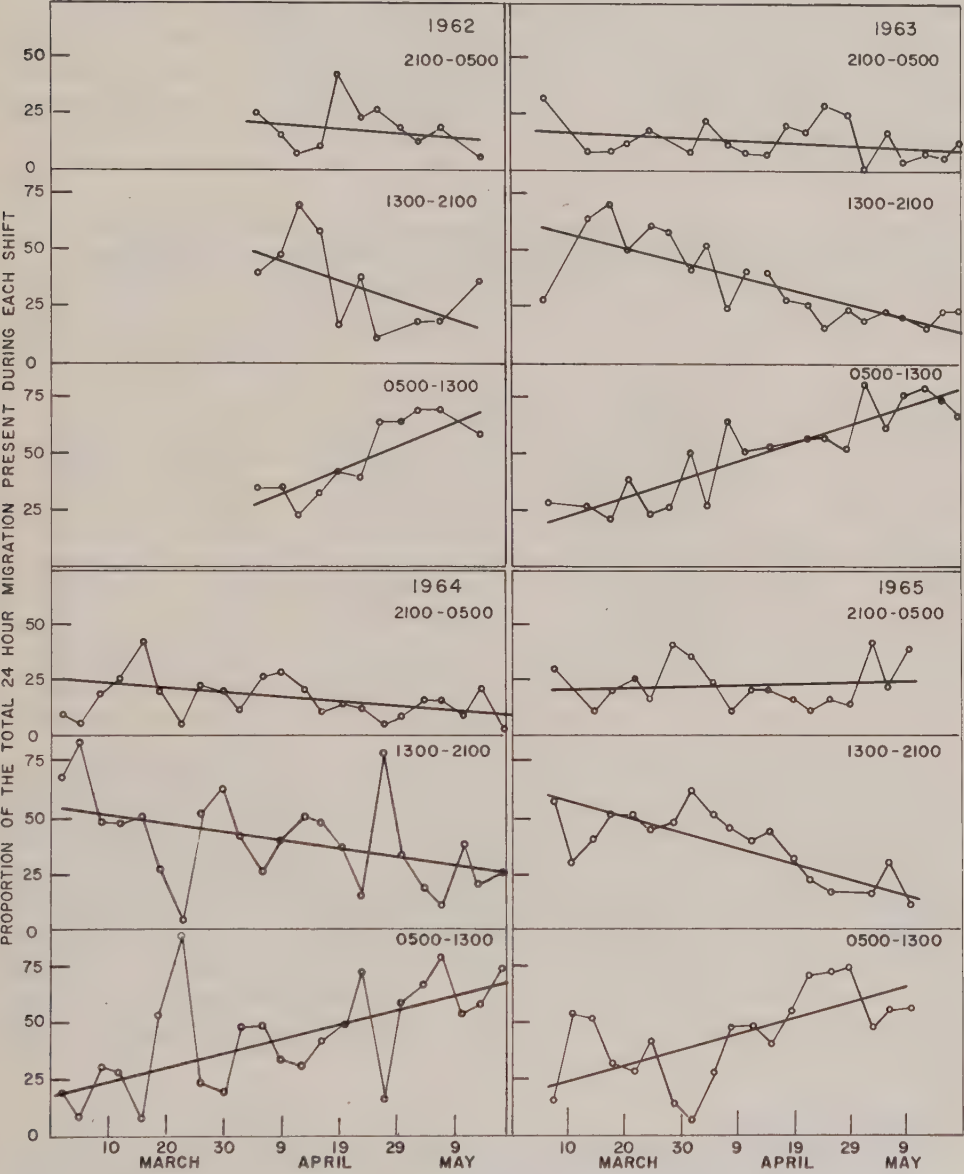


FIGURE 12. Seasonal changes in the proportion of chum salmon fry present during each eight-hour shift, 1962-1965.

The percentages calculated for each shift in each 24-hour test period are presented by year in Figure 12. Straight lines superimposed upon the data represent the calculated line of best fit for each set of data, and the calculated equations are presented in Table X. As indicated by the calculated trend lines, seasonal changes in the proportion of the total 24-hour migration present during each shift occurred in a similar manner each year. The proportion of the total daily catch which was recorded during the standard shift demonstrated a significant increase each year as the season progressed, while the proportion present during each afternoon shift declined significantly as the season advanced. Results of data obtained from the night shifts exhibited slight downward trends in three of the four years, but in effect the proportion present during this shift remained relatively constant throughout each season. This shift in abundance, therefore, occurred primarily between the two daylight sampling periods.

Table X.

The calculated linear regressions of changes in the proportion of chum salmon fry present in each eight-hour shift of the continuous 24-hour sampling periods throughout each season.

| Year      | Shift         | Linear Equation | Coefficient of Correlation (r) | Significance Level $p = .05$ |
|-----------|---------------|-----------------|--------------------------------|------------------------------|
| 1962..... | 0500-1300 y = | $1.06x - 1.32$  | $+.82$                         | $\pm .62$                    |
|           | 1300-2100 y = | $-.85x + 72.84$ | $-.55$                         | $\pm .62$                    |
|           | 1300-2100 y = | $-.21x + 28.46$ | $-.07$                         | $\pm .62$                    |
| 1963..... | 0500-1300 y = | $.75x + 18.91$  | $+.86$                         | $\pm .44$                    |
|           | 1300-2100 y = | $-.64x + 62.83$ | $-.81$                         | $\pm .44$                    |
|           | 2100-0500 y = | $-.11x + 18.72$ | $-.28$                         | $\pm .44$                    |
| 1964..... | 0500-1300 y = | $.56x + 16.69$  | $+.60$                         | $\pm .41$                    |
|           | 1300-2100 y = | $-.34x + 55.44$ | $-.42$                         | $\pm .41$                    |
|           | 2100-0500 y = | $-.22x + 28.06$ | $-.46$                         | $\pm .41$                    |
| 1965..... | 0500-1300 y = | $.67x + 15.91$  | $+.62$                         | $\pm .46$                    |
|           | 1300-2100 y = | $-.72x + 64.05$ | $-.84$                         | $\pm .46$                    |
|           | 2100-0500 y = | $.06x + 20.05$  | $+.10$                         | $\pm .46$                    |

The most logical explanation for this shift in the time of daily peak abundance at the Mission sampling site is that the river level, and therefore velocity increases as the season advances, with the result that fry require less time to travel the distance from their point of emergence to the sampling location. The possibility also exists, however, that fry originating from the Chehalis-Harrison system emerge earlier in the season than do fry originating from the Vedder-Chilliwack system. The Chehalis-Harrison fry have farther to travel than do the Vedder-Chilliwack fish, and the change in timing of daily peak abundance recorded at the Mission sampling site could, therefore, merely be a reflection of a seasonal change in the racial composition of the chum fry migration.

### (c) *Lateral Distribution*

Catches of chum salmon fry recorded at each of the three sampling stations were considered, in 1962, to have been representative of the average lateral distribution of the fry present within the one-third section of the total 1600-foot width of

the river represented by each position. In 1963 a series of tests was conducted to establish the validity of this hypothesis, and these tests were repeated in 1964 and 1965. Four sampling stations were established within each section, one of which corresponded to the standard sampling position. Sampling was conducted at each of the four stations in rotation within one section of the river throughout an eight-hour standard shift, and a total of eight of these tests was conducted within each section each year. The catches per shift recorded at all four stations were summed and from this sum a mean catch per shift was calculated. Catches recorded during each test were adjusted to compensate for changes in the availability of fish to the mobile  $4 \times 4$  caused by seasonal changes in the proportion of fry present during the standard shift, and by seasonal fluctuations in vertical distribution. The catch per shift recorded at the standard sampling station was then expressed as a positive or negative percentage deviation from the mean catch calculated for each test, and an average deviation for the season was computed from the summed totals of the standard station catches and the calculated mean catches. Table XI presents data and calculations resulting from the tests conducted in 1964 within the section of the river represented by catches recorded at Bay 2. The results of all tests of the deviation of standard station catches from the mean lateral distribution for the three stations during 1963, 1964 and 1965 are listed in Table XII and are presented graphically in Figure 13.

The catches recorded at the standard sampling stations did exhibit substantial deviations from the calculated mean distribution within individual tests in all years. In general, the percentage deviations were large when catches were small, and conversely deviations were relatively small when catches were large (Table XII).

In 1963 the total seasonal deviation calculated for each station was small; +5.0 per cent at Bay 2, +7.0 per cent at Bay 6, and -10.6 per cent at Bay 11. In 1964 and 1965, the deviations measured at Bays 6 and 11 were not substantially different from the 1963 results. The catches recorded at the standard station in the Bay 2 section, however, were lower than the mean in six of eight tests conducted each year, and the seasonal deviations totalled -37.2 per cent in 1964 and -20.3 per cent in 1965 compared with the +5.0 per cent value calculated for 1963.

In 1962 and 1963 a row of log booms was tied along the north bank of the river, and sampling at station Bay 2 consisted of fishing the mobile gear along one side of the boom. The logs were removed prior to the start of the 1964 fry enumeration program and this permitted operation of the gear closer to the shore in both 1964 and 1965 than was possible in 1963. Considering the nature of the vertical distribution of the chum fry, it is possible that the fish deflected around the upstream end of the boom and thus were concentrated in the area sampled by the mobile gear in 1963.

#### (d) *Index of Fry Abundance*

Indices of fry migration may be calculated on the following bases: that the daily catch recorded in the sampling unit is representative of the total daily migration to the same degree that the area sampled by the equipment is representative of the total cross-sectional area of the river at the sampling site; or that the daily catch is representative of the total daily migration to the same degree that the volume of



Table XI.  
Results of lateral distribution tests conducted in the Bay 2 sampling section during 1964.

| Date of Test | Unadjusted Catch per Shift |        |        |        |        | Vertical Distribution<br>% in 0-40" | Proportion Present in Standard Shift | Adjusted Catches |         | Bay 2 Catch $\pm$ % Deviation from Average |
|--------------|----------------------------|--------|--------|--------|--------|-------------------------------------|--------------------------------------|------------------|---------|--------------------------------------------|
|              | Bay 2                      | Bay 3  | Bay 4  | Bay 5  | Total  | Average                             |                                      | Bay 2            | Average |                                            |
| Feb. 28..... | 1.7                        | 1.4    | 0.3    | 1.2    | 4.6    | 1.1                                 | 100.0                                | 8.5              | 5.5     | +54.5                                      |
| Mar. 10..... | 10.4                       | 3.1    | 5.5    | 125.1  | 144.1  | 36.0                                | 92.9                                 | 41.9             | 144.2   | -70.9                                      |
| Mar. 20..... | 5.9                        | 6.4    | 74.9   | 26.6   | 113.8  | 28.5                                | 86.3                                 | 21.1             | 102.2   | -79.4                                      |
| Mar. 31..... | 5.8                        | 2.1    | 1.1    | 13.7   | 22.7   | 5.7                                 | 79.0                                 | 19.0             | 18.8    | + 6.4                                      |
| Apr. 10..... | 259.9                      | 383.0  | 514.1  | 489.1  | 1646.1 | 420.5                               | 72.4                                 | 931.0            | 1323.0  | -29.6                                      |
| Apr. 21..... | 179.9                      | 228.1  | 314.2  | 419.1  | 1141.3 | 285.3                               | 65.2                                 | 550.7            | 873.5   | -37.0                                      |
| May 1.....   | 360.4                      | 431.0  | 505.3  | 717.0  | 2013.7 | 504.4                               | 58.6                                 | 1106.1           | 1548.2  | -28.6                                      |
| May 12.....  | 101.9                      | 487.6  | 376.3  | 195.8  | 1161.6 | 290.4                               | 51.3                                 | 321.9            | 917.5   | -64.9                                      |
| Totals.....  | 925.9                      | 1542.7 | 1791.7 | 1987.6 | 6247.9 | 1562.0                              |                                      | 3100.2           | 4932.9  | -37.2                                      |

Table XII.

A summary of the results of all lateral distribution tests conducted in 1963, 1964, and 1965.

| Test Number | Bay 2 Catch<br>per Shift | Average<br>Catch/Shift | Percentage<br>Deviation<br>from<br>Average | Bay 6 Catch<br>per Shift | Average<br>Catch/Shift | Percentage<br>Deviation<br>from<br>Average | Bay 11 Catch<br>per Shift | Average<br>Catch/Shift | Percentage<br>Deviation<br>from<br>Average |
|-------------|--------------------------|------------------------|--------------------------------------------|--------------------------|------------------------|--------------------------------------------|---------------------------|------------------------|--------------------------------------------|
| 1963-1      | 176.2                    | 85.3                   | +106.5                                     | 53.4                     | 73.3                   | -27.1                                      | —                         | —                      | —                                          |
| 2           | 216.0                    | 240.6                  | -10.2                                      | 630.4                    | 500.5                  | +26.0                                      | 212.0                     | 317.5                  | -33.2                                      |
| 3           | 525.5                    | 516.2                  | +1.8                                       | 904.4                    | 647.9                  | +39.6                                      | 453.8                     | 387.6                  | +17.1                                      |
| 4           | 1527.8                   | 1812.4                 | -15.7                                      | 1192.5                   | 1247.5                 | -4.4                                       | 702.0                     | 835.3                  | -16.0                                      |
| 5           | 3004.6                   | 2597.2                 | +15.7                                      | 847.6                    | 901.5                  | -6.0                                       | 648.0                     | 828.7                  | -21.8                                      |
| 6           | 766.0                    | 662.7                  | +15.6                                      | 275.9                    | 315.8                  | -12.6                                      | 91.4                      | 211.2                  | -56.7                                      |
| 7           | 640.8                    | 595.0                  | +7.7                                       | 285.2                    | 195.9                  | +45.6                                      | 320.1                     | 291.7                  | +9.7                                       |
| 8           | 59.8                     | 76.8                   | -22.1                                      | 49.2                     | 79.8                   | -38.3                                      | 318.5                     | 199.0                  | +60.1                                      |
| Totals      | 6916.7                   | 6586.2                 | +5.0                                       | 4238.6                   | 3962.2                 | +7.0                                       | 2745.8                    | 3071.0                 | +10.6                                      |
| 1964-1      | 8.5                      | 5.5                    | +54.5                                      | —                        | —                      | —                                          | 150.2                     | 79.6                   | +88.7                                      |
| 2           | 41.9                     | 144.2                  | -70.9                                      | 3.6                      | 21.5                   | -83.3                                      | 10.1                      | 15.0                   | -32.7                                      |
| 3           | 21.1                     | 102.2                  | -79.4                                      | 67.3                     | 76.8                   | -12.4                                      | 77.3                      | 21.0                   | +268.1                                     |
| 4           | 19.0                     | 18.8                   | +6.4                                       | 573.6                    | 527.2                  | +8.8                                       | 680.6                     | 674.0                  | +1.0                                       |
| 5           | 931.0                    | 1323.0                 | -29.6                                      | 1019.3                   | 897.8                  | +13.5                                      | 713.8                     | 722.4                  | -1.2                                       |
| 6           | 550.7                    | 873.5                  | -37.0                                      | 602.9                    | 676.6                  | -10.9                                      | 1338.5                    | 1635.6                 | -18.2                                      |
| 7           | 1106.1                   | 1548.2                 | -28.6                                      | 1866.1                   | 1687.5                 | +10.6                                      | 487.4                     | 634.3                  | -23.2                                      |
| 8           | 321.9                    | 917.5                  | -64.9                                      | 247.5                    | 234.1                  | +5.7                                       | 626.1                     | 651.2                  | -3.9                                       |
| Totals      | 3100.2                   | 4932.9                 | -37.2                                      | 4380.3                   | 4121.5                 | +6.3                                       | 4084.0                    | 4433.1                 | -7.9                                       |
| 1965-1      | 181.9                    | 168.1                  | +8.2                                       | 75.7                     | 232.6                  | -67.5                                      | 338.8                     | 187.3                  | +80.9                                      |
| 2           | 212.5                    | 234.7                  | -9.5                                       | 445.5                    | 318.3                  | +40.0                                      | 45.7                      | 41.8                   | +9.3                                       |
| 3           | 350.0                    | 363.7                  | -3.8                                       | 964.0                    | 528.4                  | +82.4                                      | 195.3                     | 327.3                  | -40.3                                      |
| 4           | 643.8                    | 553.1                  | +16.4                                      | 2010.4                   | 1639.7                 | +22.6                                      | 1372.3                    | 1699.4                 | -19.2                                      |
| 5           | 2200.6                   | 3159.6                 | -30.4                                      | 3739.8                   | 3730.7                 | +0.2                                       | 936.3                     | 579.1                  | +61.7                                      |
| 6           | 775.5                    | 857.3                  | -9.5                                       | 458.0                    | 540.5                  | -15.3                                      | 292.0                     | 292.0                  | 0.3                                        |
| 7           | 238.4                    | 306.5                  | -22.2                                      | 336.0                    | 369.3                  | -9.0                                       | 449.9                     | 299.7                  | +50.1                                      |
| 8           | 80.3                     | 230.7                  | -65.2                                      | —                        | —                      | —                                          | —                         | —                      | —                                          |
| Totals      | 4683.0                   | 5873.7                 | -20.3                                      | 8029.4                   | 7359.5                 | +9.1                                       | 3630.3                    | 3427.4                 | +5.9                                       |

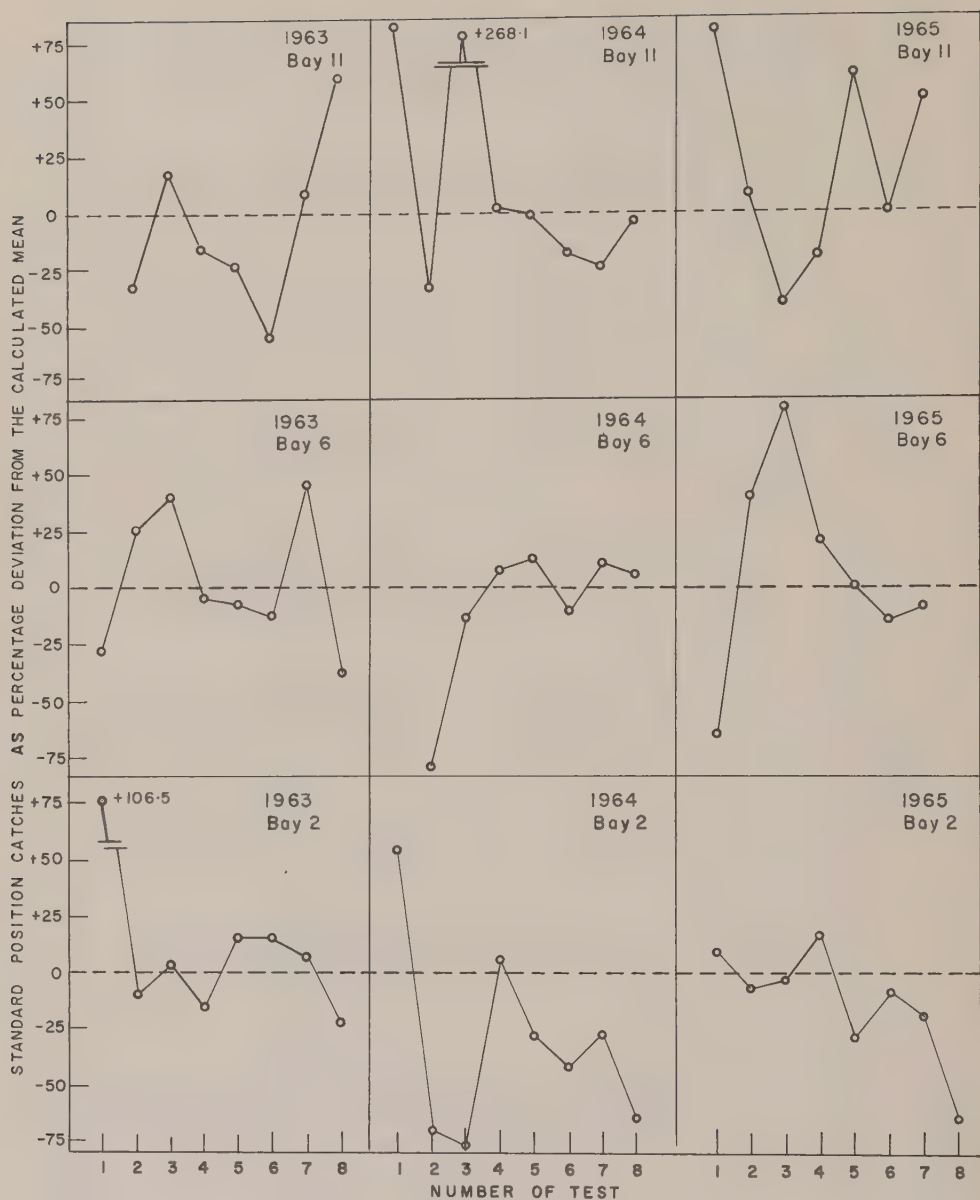


FIGURE 13. The percentage deviation of catches recorded at the standard sampling station from mean catches calculated from results recorded at four stations within each sampling section, in 1963, 1964, and 1965.

water sampled by the unit is representative of the total daily discharge. For the purpose of this analysis the first method has been adopted for the following reasons: (1) the vertical distribution studies were limited to the surface 13 feet of water; (2) results of these studies indicated that the fry, rather than being equally distributed from water surface to river bed, were actually concentrated to a large degree within



the surface 40 inches; and (3) daily discharges are affected by tidal inflow and are not measured at the sampling site.

In order to calculate an index of abundance based upon the catches of chum salmon fry recorded in the mobile  $4 \times 4$  unit during the standard daily shift, the assumption has been made that all fry migrated within the surface to 13 feet 4 inches depth range fished by the vertical sampling unit. This assumption is not true, as has been indicated previously by the results obtained in the fixed vertical sampling unit which operated throughout the entire depth of the river during 1964. The distribution demonstrated by the chum salmon fry particularly during the standard shift, however, suggested that a relatively small proportion of the total migration, probably in the order of 10 to 15 per cent, travelled deeper than the limits of the equipment. The effect of this inability to measure the total vertical distribution is that the calculated index of abundance is lower than the actual total annual abundance of chum salmon fry.

The following calculations were used to convert the catches recorded in the mobile  $4 \times 4$  at each sampling position during the standard sampling shift to an index of the total daily fry migration:

(1) Daily average catches per 15-minute run were first calculated for each sampling position.

(2) The calculated average catches per 15-minute run then adjusted for the effects of varying river velocities. The mobile gear was operated at a constant velocity throughout each season, and obviously fishing position was not maintained during periods that the river velocities were lesser or greater than the constant sampling velocity. In order to calculate a daily index of fry abundance on the basis of a catch per unit of cross-sectional area fished, sampling was considered to have taken place at a fixed position rather than at a fixed velocity. During periods when actual river velocities were lower than the speed maintained by the mobile  $4 \times 4$ , a greater volume of water was sampled than would have been had the gear been maintained in a fixed position for each 15-minute fishing period. The catches recorded during these times, therefore, were higher than they should have been. Conversely, during periods when the actual river velocities were greater than the sampling speed, a lesser volume of water was sampled than would have been had the rig been maintained at a fixed position and catches, therefore, were smaller than they should have been. In order to adjust for these differences in volumes of water sampled during each 15-minute run, the average net distance per run travelled upstream or downstream from the starting position was expressed in minutes of fishing time which were added to or subtracted from the standard 15-minute fishing period. Actual catches per run were then adjusted by the same degree that the sampling time had been adjusted. For example:

(a) Bay 6, April 17, 1965

average catch per run = 98.8

average net distance per run from starting position = +825 feet

time required to travel 825 feet at 2.73 feet per second = 5.03 minutes

$$\therefore \text{adjusted catch} = 98.00 \times \frac{15 - 5.03}{15} = 65.7$$

(b) Bay 6, April 28, 1965

average catch per run = 48.00

average net distance per run from starting position = -825 feet

time required to travel 825 feet at 2.73 feet per second = 5.03 minutes

$$\therefore \text{adjusted catch} = 48.00 \times \frac{15 + 5.03}{15} = 64.1$$

(3) The catches per 15-minute run, once adjusted in the manner described above, were then multiplied by 32 to provide calculated catches per standard shift (i.e. four 15-minute runs per hour and eight hours per shift).

(4) The calculated catches per standard shift were then adjusted for seasonal changes in vertical distribution so as to be representative of catches that would have been recorded had 100 per cent of the fry been available within the surface 40 inches of water. During the years 1962 and 1964 seasonal changes in the proportion of fry present in the surface to 40-inch depth during the standard shift were best described by calculated linear regressions. The proportion of fry present in the surface level on each day was calculated from the regression equations in both 1962 and 1964. For example:

the 1962 regression equation calculated for the standard shift was  $y = -.74x + 101.56$  where  $x$  = sampling day and  $y$  = the percentage of fry present in the surface 40 inches during the standard sampling shift on day  $x$ .

April 5 = sampling day 28 =  $x$ ;

$$y = -.74(28) + 101.56 = 80.84$$

the unadjusted catch per shift = 553.2, which represented, therefore, 80.8 per cent of the total available;

$$\text{the adjusted catch per shift, then} = \frac{100}{80.4} \times 553.2 = 688.0$$

In 1963 and 1965 the vertical distribution did not demonstrate significant seasonal changes, so the seasonal average proportions of fry available in the surface to 40-inch level were used to adjust the standard shift catches recorded in those years.

(5) The standard shift catches after adjustment for seasonal changes in vertical distribution were then adjusted for seasonal changes in diel periodicity. As discussed in a preceding section of this report the percentage of the total 24-hour migration which occurred during the standard shift demonstrated a significant increase as each season progressed. Linear regressions were calculated from the data as has previously been described, and the equations were in turn used to calculate the proportion of each day's migration which occurred during each standard shift period. The adjusted catches per standard shift were then further adjusted so as to represent catches that would have been recorded had the entire daily migration occurred during the standard shift. For example:

April 5, 1962, adjusted catch per shift = 688.0 regression equation where  $x$  = sampling day and  $y$  = proportion of total migration present during standard shift;  $y = 1.06x - 1.32$

$$\text{April 5} = \text{sampling day } 28 = x; y = 1.06(28) - 1.32 = 28.4$$

the calculated catch of 688.0 represented, therefore, 28.4 per cent of the total daily migration; the final adjusted catch, then =  $\frac{100}{28.4} \times 688.0 = 2,423.0$

The actual catches of chum salmon fry recorded in the mobile  $4 \times 4$  have been adjusted to take into consideration seasonal changes in vertical distribution and diel periodicity. The final adjusted catches, therefore, are representative of catches that would have been recorded in the mobile  $4 \times 4$  on the basis that all the fish were present in the surface to 40-inch level and that the total daily migration occurred during the standard shift. Sampling was conducted at three stations, and catches recorded at each position were assumed to have been representative of the abundance of fry present within an arbitrary one-third of the 1600-foot width of the river.

The mobile  $4 \times 4$  sampled an area 48 inches wide by 40 inches deep, which totals 1920 square inches. On the basis that catches have been adjusted so as to represent the total vertical distribution of the fish, the cross-sectional area of each sampling site within which all the fry migrate, totals  $(\frac{1580' \times 12''}{3}) \times 40'' = 252,800$  square inches. The daily index of the abundance of fry migrating past each site, therefore =  $\frac{252,800}{1920} \times \text{total adjusted daily catch} = 131.7 \times \text{total adjusted daily catch}$ .

On the basis of the foregoing technique, therefore, annual indices of chum salmon fry abundance have been calculated for the years 1962 to 1965 inclusive. The resultant figures are presented in Table XIII, which also includes the parent escapement for each of the respective fry production years.

Table XIII.

A comparison of annual chum salmon escapements with the calculated annual indices of fry production.

| Parent Escapement |         | Index of Fry Abundance |            |
|-------------------|---------|------------------------|------------|
| Year              | Number  | Year                   | Number     |
| 1961.....         | 164,200 | 1962.....              | 12,204,000 |
| 1962.....         | 180,200 | 1963.....              | 20,144,000 |
| 1963.....         | 214,200 | 1964.....              | 25,923,000 |
| 1964.....         | 325,400 | 1965.....              | 31,207,000 |

## Discussion

The operational problems involved with sampling seaward migrating chum salmon fry in the Fraser River at Mission, B.C., have largely been overcome through the development of mobile trapping gear. Sampling results have indicated that the mobile equipment operated far more efficiently than the stationary gear at this particular location, in view of the fact that it eliminated the adverse effects of tidal currents on river velocities, reduced navigational hazards, and permitted the development of a particularly economical technique for assessing the production of salmon fry from this large river system.



Daily and seasonal variations in the vertical distribution of the seaward migrating chum salmon fry were measured during each year of the study. The average seasonal distribution of the fry within the surface thirteen feet of water during the standard sampling shift was similar in all four years, in that between 65 and 78 per cent of the fry migrated in the surface to 40-inch depth range. During the afternoon and night sampling periods, however, the proportions found at all deeper levels tended to increase, although the greatest concentration still occurred within the surface to 40-inch level.

The changes in the distribution from one sampling shift to another probably affected the accuracy of the calculated indices of abundance. During the standard shift the data indicate that some fish travelled deeper than the limits of the sampling equipment, although the nature of the distribution suggests that this proportion would have been small. Adjustment of actual catches at the surface to 40-inch level recorded in the mobile  $4 \times 4$  by the measured proportion of fry present in that level tends to result in a calculated total abundance which is lower than the actual abundance. The vertical distribution data obtained during the afternoon and night shifts were used to adjust mobile  $4 \times 4$  catches for the calculation of the proportion of each 24-hour migration present during each sampling shift. The dispersal of a greater proportion of fry to depths beyond the limit of the sampling unit apparently occurred during these shifts, and the result of this dispersal tends to add to the type of error already described.

As the 1962 and 1964 seasons advanced, the proportion of fry present in the surface level progressively decreased, but this trend was not apparent in either 1963 or 1965. This decrease also occurred during the afternoon and night shifts in 1962 and 1964, but not to the same degree that was apparent during the standard shift. No particular explanation can be given for this apparent anomaly in behaviour, but the possibility has been considered that the distribution of the chum salmon fry was affected by the distribution of the more abundant pink salmon fry which are present only during even-numbered years.

The diel behaviour of the migrants was also assessed during each year. Results indicated that the peak period of migration occurred during the early afternoon at the beginning of the season, but as the season advanced the peak occurred progressively earlier in the day. The proportion of the total daily migration which took place during the night did not exhibit a significant trend during any season. McDonald (1960)<sup>6</sup> reports that in general, fry migration occurred nocturnally where the migration distances were short, but that some daylight migration, particularly of chum and pink salmon fry, occurred where migration distances were longer. In the Fraser River at Mission, the nocturnal pattern of migration apparently has all but disappeared as less than 20 per cent of the total migration was recorded during the night hours.

In addition to an assessment of the vertical distribution and diel periodicity, studies of changes in the lateral distribution of the chum salmon fry were conducted during 1963, 1964, and 1965. Results indicated that the fry were distributed over the entire width of the river throughout the season. In 1963 catches recorded at all three sampling locations were not significantly different from the mean distribution and this situation was similar in 1964 and 1965 at two of the three stations. The

catches recorded at the north bank or Bay 2 station in 1964 and 1965 did demonstrate significant variations from the mean lateral distribution calculated within the northern one-third of the width of the river. This variation in those two years may have resulted in part at least from the removal of log booms in 1964 which permitted operation of the mobile gear closer to the shore than was possible in 1963.

The production of chum salmon fry from the Fraser River has been calculated for the years 1962 to 1965 inclusive from the results of the sampling program conducted near Mission City. The figures cannot be considered as absolute measures of fry production although a concerted effort has been made to reduce sampling error to a minimum. They do represent, however, valuable indices of abundance and as such have been used as comparative measures of annual fry production. The 1965 index of fry output, for example, represented a significant increase over the indices calculated for any of the previous years.

In summary, the technique as described has provided an efficient and apparently effective method for sampling seaward migrant salmon fry in the upper tidal reaches of a large river system, with a relatively small amount of effort.

### Acknowledgments

Mr. E. Vernon and Mr. L. Verhoeven, of the International Pacific Salmon Fisheries Commission, were responsible for the initial use of mobile equipment. Technician J. L. Scott of the Department of Fisheries of Canada was instrumental in modifying the original mobile sampling equipment. Special mention should be made of the contribution to the program provided by the owner and operator of the chartered vessel, Mr. J. Zart. The author is indebted to Mr. R. A. Crouter, senior biologist of the Department, for his helpful suggestions in editing the manuscript.

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# Depth and Velocity as a Factor in Stream Rearing and Production of Juvenile Coho Salmon

by

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## Abstract

Coho salmon smolt production was measured in four artificial stream channels 200 feet long by 20 feet wide. Two years' data are presented on the effect of depth and velocity on fish food production, smolt production and fish behaviour. A known number of wild coho fry were introduced to each channel and allowed to take up residence in the channel on a volitional basis.

The amount of downstream migration was influenced by the availability of low velocity water. Over twice as many fry remained in a pool-like environment as in a riffle-like condition; an intermediate number remained when the depth-velocity situation was somewhere between pool and riffle. Whereas fish preferred the pool-like environment, fish food production was much higher in the riffle-like environment. The most coho smolt production occurred in a channel composed of one-half riffle and one-half pool. Differences in behaviour were noted between coho fry which had migrated upstream of their place of emergence and fry which had moved downstream from their place of emergence.

## Introduction

One of the difficult fisheries problems that arose from the recent series of hydro-electric diversion projects in British Columbia concerned reduced flows in streams rearing juvenile coho salmon (*Oncorhynchus kisutch*). The construction of the experimental channels adjacent to the Robertson Creek Channel (Lucas, 1960) provided an opportunity to investigate the stream rearing requirements of coho juveniles. This paper presents the results of two years experiments on this problem and provides a description of the experimental facilities.

There is considerable evidence to show that coho salmon production is often governed by the extent and character of the freshwater rearing area. Salo and Bayliff (1958), Hunter (1959) and Chapman (1962), all showed that coho smolt migration from a given stream was relatively constant and bore no particular relationship to the parent runs. Neave (1949) and Smoker (1953) showed strong positive correlations between annual catches of coho salmon and stream runoff in the year of stream

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residence for given year classes. Although it is well established that the stream environment plays an important role in governing coho salmon production, quantitative ecological data on the dynamics of smolt production is lacking.

Usually, to obtain information of this kind, a long series of observations is made according to some definite plan. Changes which occur are explained on the basis of correlations among the quantities measured and on known principles of biology, physics and chemistry. Since there are so many variable factors in the natural environment, it is often difficult to collect enough data to permit the thorough statistical analysis that is needed for separating the effects of the factors. The experimental control offered by the Robertson Creek Experimental Channels provides a means by which the effects of environmental changes on coho smolt production can be more accurately evaluated.

The experimental channels are located on Robertson Creek, a secondary outlet of Great Central Lake on the west coast of Vancouver Island, British Columbia. Construction of the channels was completed in 1960 and a preliminary description was given by Lucas (1960) in a paper describing the over-all development of Robertson Creek as an artificial spawning channel and fish cultural research area.

The experimental rearing facilities (Figure 1) consist of four parallel channels 200 feet long by 20 feet wide separated by gravel and earth dykes. Individual inlet



FIGURE 1. *Photograph of the four experimental channels divided to make eight sub-channels.*

and outlet works provide independent hydraulic control for each channel. Any portion of the Robertson Creek flow can be diverted into one or all of the rearing channels. The substrata in all channels is composed of gravel ranging in size from 3/4 to 4 inches in diameter. Channel No. 1 is designed to provide shallow depth, in the range of from four to twelve inches. Channels No. 2 and 3 are designed to carry a normal depth of one and one-half feet, while Channel No. 4 has a normal depth of three feet nine inches.

Each of the four channels is divided longitudinally by a centre wall, forming two sub-channels 200 feet long by 10 feet wide. The water-surface area of each sub-channel in channels 1, 2 and 3 is 250 square yards, and 350 square yards in the deeper channel 4. Each sub-channel has inclined screen traps at the upstream and downstream ends. The upstream traps prevent extraneous fish from entering the channels, while the downstream traps allow for the capture of emigrants. Figure 2 shows the basic plan of the eight sub-channel layouts.

The avenues open to research by such a facility are almost limitless. Although it was recognized that an investigation on the freshwater rearing requirements of coho salmon would eventually consider the interrelationships between many factors, it was decided to limit the early investigations to the effects of the physical environment on the dynamics of coho smolt production. Consequently, the initial experiments were designed to examine the relative contribution of pool and riffle in smolt production. Since the production of age 1 smolts was used as the primary criteria in evaluating these tests, each experiment extended over a year-long period. In addition to these long-term experiments, short-term tests were conducted to evaluate the effects of cover and shade on the downstream movement of coho juveniles and to examine behavioural differences in upstream and downstream migrating coho fry.

## Methods

The rearing channels were stocked with wild coho fry obtained during April of each year from Robertson Creek. The fry were collected by dip-netting along the margins of the creek during the peak of fry emergence. A few downstream migrating fry were caught in the inclined-plane screens at the entrance of the rearing channels. The fry were randomly mixed and held in liveboxes until their release into the rearing channels. All held fish were fed a dry commercial fish-food four times per day.

A representative sample was weighed and measured from each group of fish prior to their introduction into the rearing channels. Each introduction was made in the middle portion of the sub-channels and considerable effort was made to keep stocking procedures identical. Fish placed in the channels could leave by passing over the downstream stoplogs, but in so doing were captured for enumeration purposes by the downstream inclined-plane traps. Their exit was blocked at the upstream end of each channel by the upstream inclined-plane traps. Fish emigrating from the channels within 24 hours following introduction were replaced into their respective sub-channels. After this initial adjustment period, all emigrants were trapped and counted at the downstream screens and then held in liveboxes for future experiments. Since colonization of each rearing channel was of a volitional nature, emigration would reflect the initial holding capacity of each rearing channel and smolts produced in the channels could migrate downstream in a natural manner.



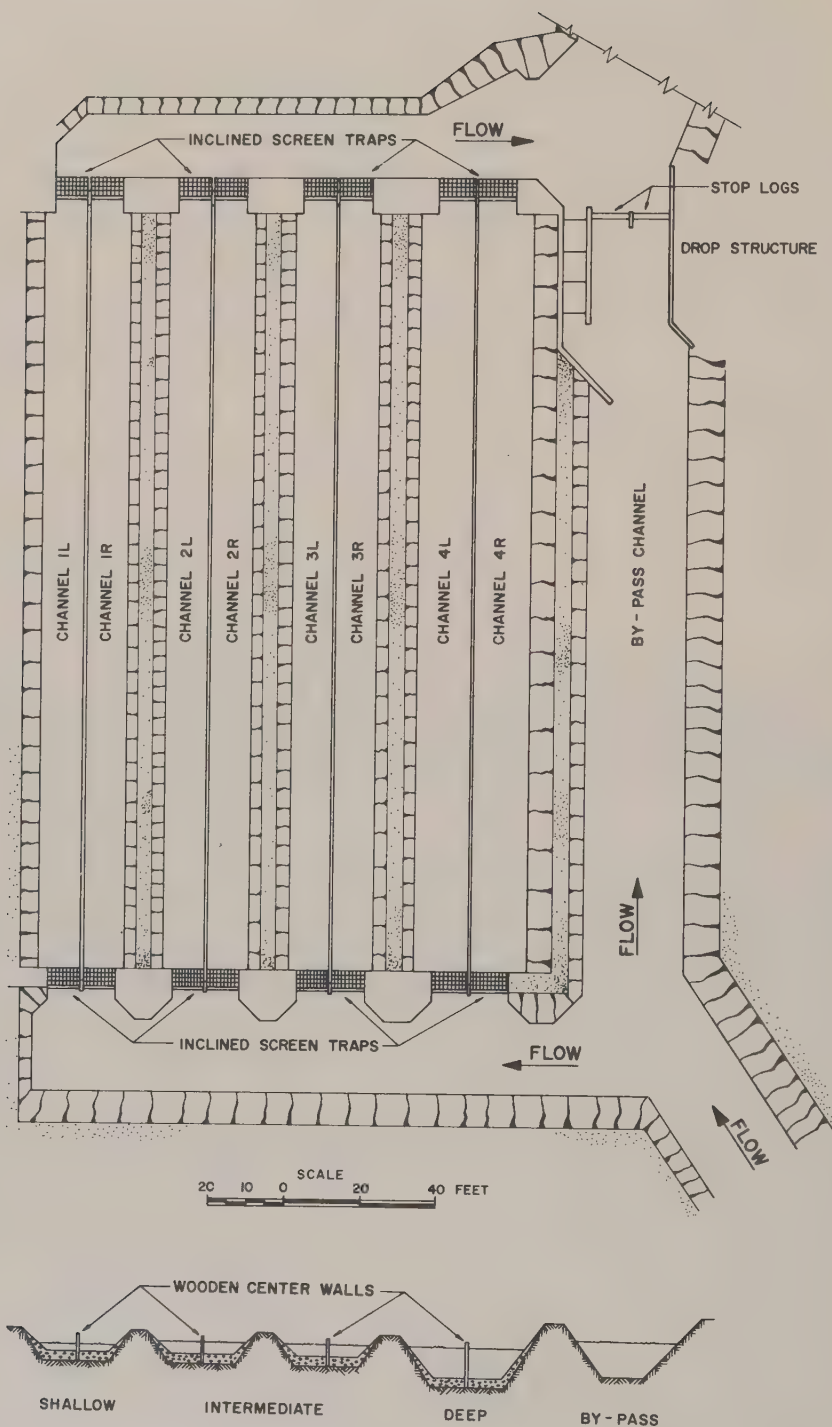


FIGURE 2. Basic plan of the rearing channels.

### *Pool and Riffle Experiment*

Hydraulic conditions were established in the spring of 1962 which provided equal inflows of 10 cfs into three of the experimental channels. The following depth-velocity conditions were created:

*Channel 1:* a riffle condition. The depth in this channel was 0.5 feet and the mean velocity was 1.2 feet per second.

*Channel 3:* an intermediate condition. The depth in this channel was 1.4 feet and the mean velocity was 0.6 feet per second.

*Channel 4:* a pool condition. The depth in this channel was 3.8 feet and the mean velocity 0.1 feet per second.

In the spring of 1963 the pool-like and riffle-like conditions were repeated in channels 1 and 4, but in place of the intermediate depth velocity situation tested in 1962, a channel composed of one-half riffle and one-half pool was tested. The upstream half consisted of a 100-foot-long riffle section and the downstream half consisted of a 100-foot-long pool section. Equal inflows of 9.5 cfs to each rearing channel in 1963 provided the following hydraulic conditions:

*Channel 1:* a riffle condition. The depth was 0.4 feet and the mean velocity was 1.2 feet per second.

*Channel 2:* pool and riffle combined. The depth in the pool section was 2.5 feet and the velocity 0.2 feet per second. The depth in the riffle section was 0.8 feet and the mean velocity 0.6 feet per second.

*Channel 4:* a pool condition. The depth in this channel was 3.6 feet and the mean velocity was 0.1 feet per second.

All channels, during both years of testing, were divided longitudinally by wooden centre walls so that duplicate tests were carried out on each hydraulic condition. The sub-channels were designated as left or right when looking downstream. The sub-channels were stocked by releasing into each sub-channel numbers of coho fry believed to be in excess of the holding capacity, the approximate holding capacity having been established in preliminary tests. The stocking procedure was similar each year; a large initial release was followed by two smaller releases about one week apart, making a total of three separate releases each year.

In 1962 the first release of experimental fish into the rearing channels was made on May 24 and 25. On May 24, 1,000 coho fry were released into sub-channels 1-left, 3-left and 4-left. The next day, the procedure was repeated with the right sub-channels. The one day delay served as a check on the "fish-tightness" of the centre walls. These fish, 6,000 in total, averaged 0.7 grams in weight. The second release of coho fry into the six sub-channels was made on June 1. Two hundred and fifty fry were introduced into each sub-channel. These fish, 1,500 in total, averaged 0.6 grams. A third and final release of 2,850 coho fry was made on June 6, 475 into each sub-channel. These fish had a mean weight of 0.8 grams. Therefore in the 1962 experiment a total of 1,725 fish, with a mean weight of 0.7 grams, was introduced into each sub-channel.

In 1963 the stocking procedure was repeated. The first, second and third releases contained 1,000, 250 and 200 fish, respectively, making a total of 1,450 fish to each

sub-channel. The fish in 1963 were in excellent condition and weighed an average of 1.0 grams, a substantial increase over the mean weight of 0.7 grams of fry introduced in 1962.

### *Short Term Tests*

In addition to the relatively long-term pool and riffle experiment conducted during 1962 and 1963, a series of short-term tests was conducted in one of the rearing channels set aside each year for this purpose. In 1962 these experiments were carried out in channel 2 and in 1963 in channel 3. The hydraulic conditions were similar in both years. In 1962, 10 cfs produced an average depth of 1.3 feet and an average velocity of 0.5 feet per second in channel 2. In 1963, 9.6 cfs produced an average depth of 1.5 feet and a mean velocity of 0.4 feet per second in channel 3.

### *Environmental Measurements*

In order to help interpret some of the results of the rearing experiments certain measurements of the rearing channel environment were recorded. Water temperature was recorded on a continuous thermograph recorder placed in channel 4-left. In addition, hand thermometer readings were taken twice each day to check the thermograph and to detect differences in the water temperature between channels.

Bottom fauna was sampled periodically throughout the study by two methods. Wooden trays were buried in the gravel flush with the surface and filled with regular rearing channel gravel. These trays were removed from time to time and the gravel in them examined for macroscopic organisms. This was the only method used for examining bottom fauna in the pool-like sections. In the swifter flowing sections of the rearing channels a specially designed bottom fauna sampler was used as well as the bottom fauna trays. The special sampler was fashioned after one described by Waters and Knap (1961) and incorporated a circular frame 13.56 inches in diameter, one square foot in area. Bottom organisms within this area were sampled without loss of organisms or without the entrance of drift organisms since the area was surrounded by nylon netting with a mesh size of 471 microns, 39 meshes to the inch. The samples were weighed on a triple beam balance after lightly blotting with filter paper.

## Results

### *General Behaviour of Introduced Fish*

The initial behaviour of coho fry after their release into the rearing channels did not vary significantly during the dozens of introductions made over the two-year study period. After release into their respective channels the fry exhibited an almost immediate upstream migration. In the high velocity channel the fry moved upstream along the banks and along the wooden centre wall in two narrow bands. In the lower velocity situations the upstream movement occurred in small, loose aggregates at various depths and at various locations in the channels. Upon reaching the upstream screens, a distance of 100 feet from the point of release, the fry would hold position in the immediate area below the screens for a period of from 20 to 30 minutes. After this holding period, groups of fry would begin actively swimming downstream, with some of these groups swimming all the way down to the lower end of the channels where they stopped and held position. Within two or three hours



from the time of introduction these groups of coho fry would disperse and many individuals could be seen defending discrete territories. During this dispersal period emigration from the channels would begin, the first emigrants appearing on the downstream screens about one hour after the time of the initial release.

Most of the emigration occurred during the first day or two. As mentioned previously, fish emigrating during the first 24 hours were re-introduced, but the second day's emigration was usually of the same magnitude. After this initial exodus, the emigration rate decreased until only one or two fish would leave any given channel per day.

Although this investigation was not intended to provide quantitative observations on juvenile coho behaviour, it became obvious that differences in behaviour existed between fish remaining in the pool-like environment and fish remaining in the riffle-like environment.

In the low velocity situation provided in channel 4, extensive cruising throughout the channel was noted and agonistic behaviour was limited to a relatively few individuals who positioned themselves in local areas of increased velocity. One of these local areas of moving water was located immediately upstream of the downstream stoplogs where the water accelerated as it passed over the stoplogs. A second area of increased velocity was located just below the upstream inclined-screen traps where the inflow created an extensive area of moving water.

In the riffle-like environment coho tended to remain fixed to a given location in the channel, usually in close proximity to the gravel bottom. Agonistic behaviour was more often observed and the coho juveniles appeared to be more or less evenly distributed throughout the entire channel.

Kalleberg (1958) found that reduction in velocity in his large stream tank tended to cause Atlantic salmon and brown trout to rise away from contact with the stream bottom and move about the aquarium observation channel.

A difference in feeding behaviour was also noted in fish inhabiting the riffle-like environment and those living in the pool-like environment. Young coho were observed feeding within minutes, and in one instance, seconds, after they were released into the experimental rearing channels. In the swift flowing waters, they seemed to depend primarily on the "organic drift" (Müller, 1954) brought to them by the current. Short, swift, darting movements captured the prey as it drifted within range of the young coho. In the deep, slow-flowing environment the young fish were observed feeding on flying insects, in some instances chasing a prospective prey for several yards before finally capturing it with an accurate, upward rush through the surface of the water.

### *The 1962 Pool and Riffle Experiment*

Since identical numbers of coho fry were placed in each rearing channel, emigration reflected the holding capacity of the three hydraulic situations under study. Figure 3 depicts the average number of coho juveniles present in each of the three depth-velocity situations beginning with the last two weeks of June (after the initial surge of emigration from the third and final release) until the following May. These data represent the numbers of coho juveniles remaining in the channels after emigration, but do not take into account the natural mortality occurring within the rearing channels.

The initial holding capacity of the three hydraulic conditions varied directly with depth and inversely with the velocity. The shallow-swift situation held an initial population of approximately 420 fish per sub-channel, while the deep-slow situation held approximately 980 fish per sub-channel. The intermediate depth-velocity situation held approximately 790 fish per sub-channel.

During the latter part of July and throughout August the emigration rate increased, resulting in a decrease in the population size in all channels. This period of increased emigration corresponded to a period of high water temperatures. By September, emigration in channels 3 and 4 had slowed considerably, although fish continued to leave channel 1 throughout October and November. In fact almost all the fish present in the shallow-swift channel emigrated by mid-December. The following April and May saw emigration increase once again in channels 3 and 4 as the juveniles began their migration to the sea as one-year-old smolts. Since most of the fish had left channel 1 during the previous fall, the smolt production from this channel was very low.

On May 29 each of the channels was poisoned with Rotenone to remove all the remaining fish. This was done to prepare the channels for the next year's rearing experiments. The following table summarizes the number of smolts migrating during April and May, as well as the number of residual fish in each channel on the day they were poisoned.

|                           | Channel 1 |       | Channel 3 |       | Channel 4 |       |
|---------------------------|-----------|-------|-----------|-------|-----------|-------|
|                           | Left      | Right | Left      | Right | Left      | Right |
| April and May Smolts..... | 2         | 1     | 17        | 21    | 49        | 42    |
| Residuals.....            | 0         | 1     | 6         | 11    | 35        | 42    |
| Total.....                | 2         | 2     | 23        | 32    | 84        | 84    |

If residuals are included, fish production amounted to 0.8, 11 and 24 fish per 100 square yards of water-surface area in channels 1, 3, and 4, respectively. The production on an area basis from rearing channel 4 was about equal to that estimated for good coho salmon streams in Washington State and British Columbia. The large number of residuals in channel 4, however, represent a questionable portion of this production, and based on April and May smolts only, the production of channel 4 would be reduced by about one-half.

Although smolt production was relatively high from the pool-like channel, the mean weight of these fish was considerably less than that of naturally migrating smolts. In comparison, the smolts produced in channel 1, the riffle-like environment, were slightly larger than naturally produced smolts. Periodic sampling of coho smolts produced naturally in Robertson Creek showed them to have a mean weight of 11.0 grams. The mean weight of the coho smolts migrating from channels 1, 3 and 4 during April and May, 1962 was 12.0, 6.3 and 4.4 grams, respectively. The marked difference in size of the smolts produced under the three depth-velocity situations tempts conjecture.

Sampling of the inflow for stream drift indicated that almost no macroscopic fish-food organisms entered the rearing channels. The inclined-screen traps were sufficiently fine-meshed to prevent a significant portion of the usual drift organisms from entering the experimental channels. Stream drift in Robertson Creek was present and showed a diurnal fluctuation in abundance similar to that reported by Waters (1962). It is believed, therefore, that fish rearing in the channels were largely dependent upon food produced in the channels and to a lesser extent, upon adult insects landing or flying near the surface of the water.

Bottom fauna sampling showed a marked difference in quality and quantity of the standing crop present in the different channels (Table I). The shallow-swift channel had about 10 times the standing crop of the intermediate depth-velocity channel, and about 18 times that of the deep-slow velocity channel. Caddisfly larvae dominated the riffle samples, while snails were almost the only bottom organisms found in the pool-like channel.

Table I

Bottom fauna per square foot during the period July to November, 1962 in rearing channels 1, 3 and 4.

| Channel                       | 1    | 3     | 4    |
|-------------------------------|------|-------|------|
| Number of samples.....        | 13   | 13    | 12   |
| Mean weight in grams.....     | 0.52 | 0.05  | 0.03 |
| Greatest weight in grams..... | 1.3  | 0.20  | 0.10 |
| Least weight in grams.....    | 0.1  | trace | nil  |
| Per cent by volume:           |      |       |      |
| Caddisfly.....                | 70   | 6     | 0    |
| Mayfly.....                   | 7    | 0     | 0    |
| Stonefly.....                 | 4    | 0     | 0    |
| Snails.....                   | 11   | 81    | 98   |
| Other.....                    | 8    | 13    | 2    |

Although several fishery workers have observed that large fish populations may reduce the standing crop of bottom fauna in ponds, lakes and streams, Larkin et al. (1950). Hayne and Ball (1956), Reimers (1958) and Ruggles (1959), this does not seem a reasonable explanation for the situation present in the rearing channels. The wide difference in the physical habitat between channels seems sufficient to account for the difference in the standing crop of bottom fauna observed.

Most food production studies in streams have shown that bottom fauna production is much higher in swift flowing areas of the stream than in the slow flowing sections, Ruttner (1953). A study of a small stream in California for instance showed that 80 per cent of the total production of bottom fauna originated in riffle areas, Briggs (1949). The caddisfly larvae, which comprised the greatest potential source of fish food in the rearing channels, were a species of Hydropsychidae which are found only in rapid flowing streams. These organisms, therefore, could only be produced in the riffle-like channel 1. The small size of the one-year-old coho juveniles produced in channels 3 and 4 is believed to be due primarily to low bottom fauna production in these channels.



### *The 1963 Pool and Riffle Experiment*

Based on the results of the 1962 experiment, a combined pool and riffle condition was tested in 1963. The plan was to combine the fish holding capacity of the pool-like environment and the food producing capacity of the riffle-like environment in one channel, the upstream 100 feet being riffle and the downstream 100 feet, pool. As controls, the pool-like and riffle-like channels were repeated in 1963.

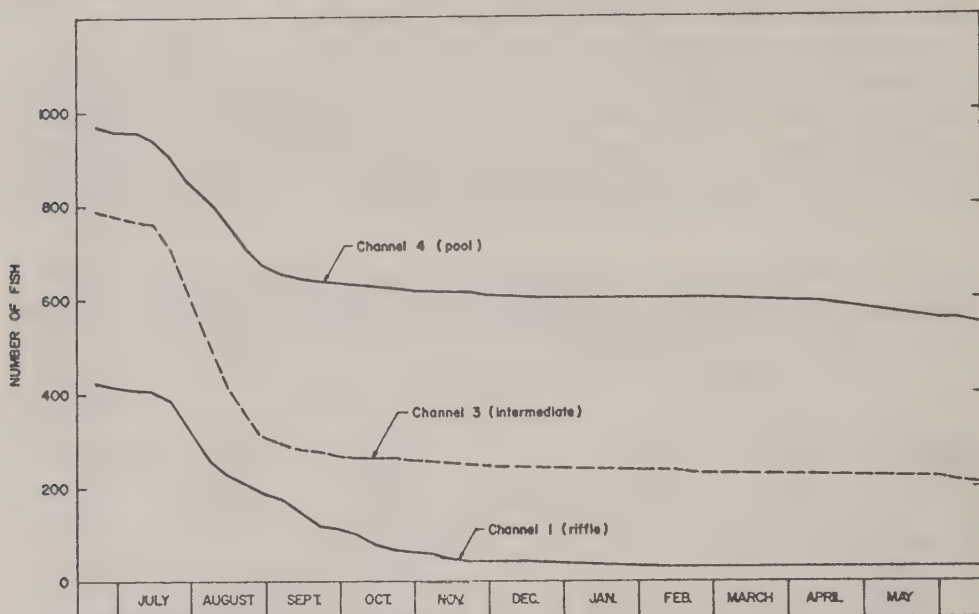


FIGURE 3. *The mean number of juvenile coho salmon remaining in each sub-channel (1962-63).*

Figure 4 depicts the average number of coho juveniles present in the three hydraulic situations from shortly after the last introduction of experimental fish until the following May. Once again, these data represent the numbers of fish remaining in the channels based on the emigration records and do not take into account the natural mortality occurring within the rearing channels.

The initial holding capacity of the pool-like channel 4 and the combined pool and riffle channel 2 was of the same magnitude. Channel 4 held an average of 1,180 fish per sub-channel and channel 2 held an average of 1,220 fish per sub-channel. The riffle condition, channel 1, held approximately 930 per sub-channel. The importance of low velocity area in governing the initial holding capacity of the rearing channels was again demonstrated. The interesting point is that the channel composed of one-half pool had an initial holding capacity as great as the channel composed entirely of pool. The fact that the initial holding capacities of all the channels was higher in 1963 than in 1962 was probably due to larger and better conditioned fry that were available for the 1963 experiment.

After an initial period of about one month, during which emigration was relatively low, the population in all channels fell swiftly, Figure 4. This resulted from large

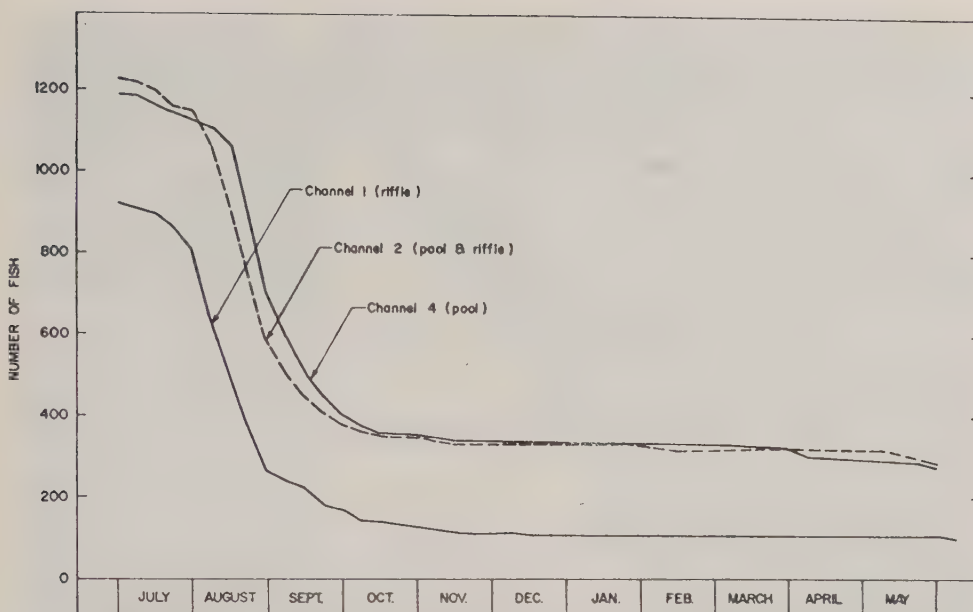


FIGURE 4. The mean number of juvenile coho salmon remaining in each sub-channel during 1963-64.

numbers of fish emigrating from all channels during August, and to a lesser extent, during September. Very little emigration occurred in channels 2 and 4 throughout the period October to March inclusive. In channel 1, however, significant numbers of coho juveniles left during October and early November. Emigration increased in all channels during May with most emigrants showing typical smolt characteristics. In general, the pattern of emigration was similar to that observed during the 1962 experiment.

The following table summarizes the number of one-year-old migrants produced from each channel and the number of residual fish remaining in each channel on June 3, 1964:

|                           | Channel 1 |       | Channel 2 |       | Channel 4 |       |
|---------------------------|-----------|-------|-----------|-------|-----------|-------|
|                           | Left      | Right | Left      | Right | Left      | Right |
| April and May Smolts..... | 3         | 6     | 33        | 35    | 35        | 30    |
| Residuals.....            | 1         | 0     | 12        | 9     | 39        | 30    |
| Total.....                | 4         | 6     | 45        | 44    | 74        | 60    |

Very few one-year-old migrants were produced in the shallow-swift channel. Most of the juvenile coho left the riffle-like environment of channel 1 during the previous fall and early winter. The yearlings produced in channel 1, however, were the largest of the fish produced in the three long-term channels, averaging 9.5 grams.

In channel 2, the half pool-half riffle channel, April and May smolt production slightly exceeded that of the pool-like channel 4. Fewer residuals remained in channel

2 than in channel 4. The mean weight of April and May smolts produced in channel 2 was 8.0 grams. The mean weight of the residuals in channel 2 was 6.6 grams.

The one-year-old migrants from channel 4 were the smallest of the fish produced in any of the long-term channels, averaging 5.3 grams during the April and May migration period. The residuals that remained in the channel on June 3 averaged 4.1 grams. Total production in the deep-slow channel, including residuals, was again the highest of the three depth velocity situations; however, based on April and May smolt production, channel 2 showed as high a production as did channel 4.

Based on the number and size of one-year-old migrants, it is evident that production in channel 2 reflected the fish holding advantages of channel 4 as well as the food availability of channel 1. Further research could profitably be directed towards investigating the relative proportion of pool and riffle required for maximum smolt production.

#### *Effect of Shade on the Initial Holding Capacity*

Since vegetation of sufficient size to provide shade was non-existent near any of the rearing channels, it was decided to test the effect of overhead shade on the initial holding capacity of channel 2 (the channel set aside during the 1962 tests for short-term experiments). Sub-channel 2 left was provided with a 4-foot wide plywood overhang 22 inches above the surface of the water and extending the full length of the sub-channel. Sub-channel 2 right was identical to sub-channel 2 left except for the omission of the shade structure. Figure 5 is a photograph showing the two sub-channels with the shade structure in place. On June 20, 1962, one thousand coho fry were released into each sub-channel. Fish that emigrated during the first 24 hours were re-introduced into their respective channels. Fish emigrating after this period were counted and held in live-boxes for future experiments.

During the first 24 hours, 644 fish left the shaded channel while only 396 fish left the unshaded channel. These fish were re-introduced into their respective channels. The next day 342 fish emigrated from the shaded channel and 248 from the unshaded. Emigration rate was low during the next five days, 20 fish leaving the shaded channel and 7 fish the unshaded channel. These results indicate that the addition of shade decreased the initial holding capacity of the experimental channel. General observations made by scuba diving in Robertson Creek showed that coho fry were not concentrated in areas of overhead shade. Apparently young coho do not tend to congregate in shaded areas, in fact they may tend to avoid areas of dense shade.

#### *Effect of Cover on the Over-Winter Rearing Capacity*

In the 1962 long-term experiment, fish left the riffle channel during the fall and early winter. General observations during the fall and winter, under natural conditions, revealed that coho juveniles disappeared from their usual haunts. Seining in areas that usually produced catches of coho were unproductive. The few coho observed during this period were seen in areas associated with dense cover. It was decided in the fall of 1963 to test the effect of cover on the over-winter rearing capacity of the short-term experimental channel by placing flat, rectangular patio blocks in one sub-channel while leaving the other sub-channel unchanged. One hundred patio blocks



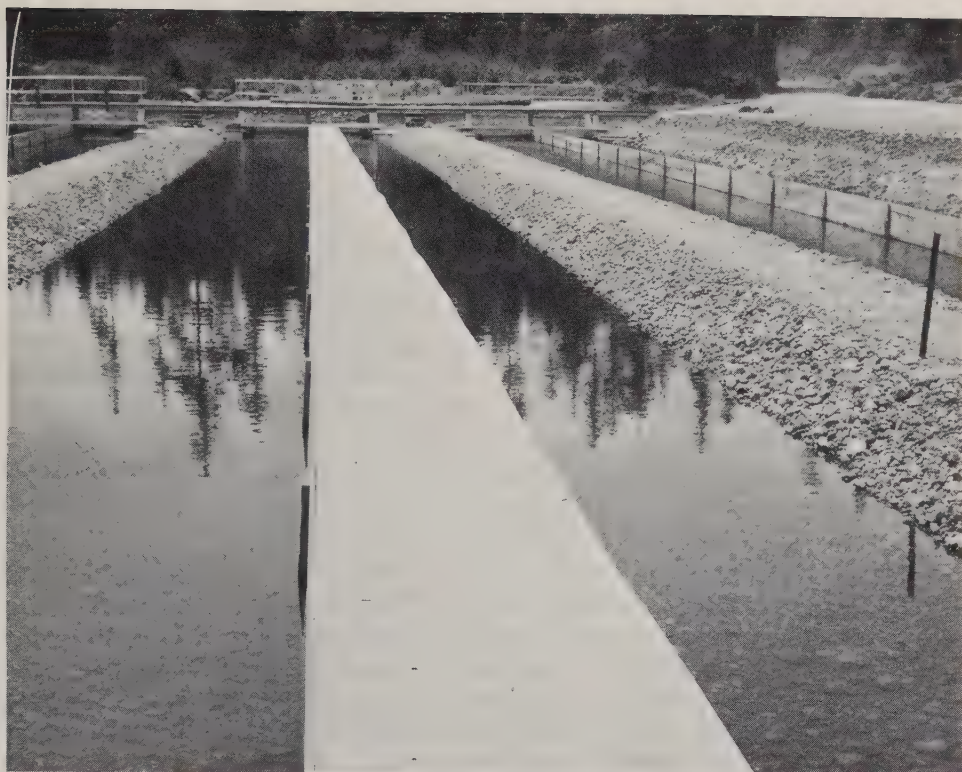


FIGURE 5. *A photograph of the short-term experimental channel in 1962 showing the plywood shade structure on one side of the centre wall.*

15½" long, 17½" wide and 1½" thick were evenly distributed throughout channel 3 left. They were placed on the bottom surface of the gravel so as to provide an area of cover under each block.

On October 9, 1963, each sub-channel was stocked with 150 coho juveniles. By January 1, 1964, 50 coho had left the sub-channel which had contained cover and 56 had left the sub-channel without cover. Ten smolts left the sub-channel containing cover in May, while 16 smolts left the channel containing no cover during the same period. Residuals present on June 3 were 6 for the sub-channel with cover and 24 for the sub-channel without cover. The mean weight of the smolts produced was 7.2 grams for each sub-channel.

The effect of cover on coho smolt production in the experimental rearing channel was the opposite to what was expected. Tarzwell (1937, 1938), Shetter et al. (1946), Ehlers (1956), Braun and Beland (1958), and Saunders and Smith (1962) have all considered cover an important factor in controlling the distribution and abundance of trout in streams. Unfortunately, none of these investigators was able to isolate the effect of cover from other stream improvement techniques employed at the same time. Boussu (1954) studied the relation between trout populations and the various kinds of natural cover in a small Montana stream; the effect of partial or complete removal of natural cover and the application of artificial cover to areas naturally

devoid of such protection. He showed a direct relationship between the presence of cover and trout production. The addition of cover under the conditions tested in the artificial rearing channels did not increase coho smolt production. Perhaps under natural conditions where interspecific competition and greater predation might be expected to occur, the addition of cover would exert a more positive role in smolt production.

#### *Behaviour Differences in Upstream and Downstream Migrating Coho Fry*

Large numbers of coho fry have often been observed moving downstream in the spring shortly after emergence. As well as this commonly observed downstream movement, an extensive upstream movement of newly emerged coho fry was observed during the spring of 1962, 1963 and 1964 in the Robertson Creek Spawning Channel. Since the spawning adults had been confined by means of a fence to a discrete section of the spawning channel, it was relatively simple to confirm this upstream movement of fry into areas above the spawning grounds. In fact this migration could be observed taking place along the margins of the creek throughout the daylight period. The downstream drift of coho fry has been suggested by Chapman (1962) to result from the aggressive behaviour of residual coho. He observed very little movement in an upstream direction.

In the spring of 1963 an experiment was designed to examine the difference in behaviour between the coho fry which were moving in large numbers downstream at night, and the fry which had moved upstream of the spawning area and were holding in pools and back eddies along the margins of Robertson Creek.

On May 14, 500 coho fry collected above the spawning area were placed on one side of the centre wall of the short-term channel and 500 coho fry collected below the spawning area were placed on the other side. By May 23, 295 of the upstream fish remained in the channel, while only 173 of the downstream fish remained. On this date the channel received an additional 410 fry to each side. The fish from this second release were all marked by notching the dorsal lobe of the caudal fin. Fish of the upstream type were placed into the sub-channel that contained the remaining downstream fish and fish of the downstream type were placed into the channel that contained the remaining upstream fish. By May 28 the populations in the two sub-channels were almost identical (307 vs 302). This was due to the fact that once again a higher proportion of upstream fish remained from the second release than of downstream fish. Emigration after the second release was almost exclusively of marked fish.

Since more of the fry originating from upstream of the spawning area remained in the experimental channel than fry originating from downstream of the spawning area, under identical conditions, there appeared to be a difference in basic behaviour between the two groups. This difference in behaviour was demonstrated when the fish were released into channels barren of fish and when they were released into the channels already containing fish.

Although there was no significant difference in size between fry collected upstream of the spawning area and fry collected downstream of the spawning area, fish that emigrated from the sub-channels were lighter in mean weight than those that remained. Therefore the initial movement of coho fry after emergence, either

upstream or downstream, did not appear to be governed by size. Subsequent displacement in the experimental channels, however, suggest that size was a factor in deciding dominance within the two groups. Chapman (loc. cit.) found slight differences in length of individual coho fry (as slight as 1 mm) was sufficient to bring about subordination of smaller fish.

In addition to size, prior residence appeared to confer a greater potential for dominance upon individual coho fry than it might otherwise have possessed. Thus, emigration after the second release was almost exclusively of marked fish. This means that fish of the upstream type had little success in displacing individuals of the downstream type once the latter had established residence in the experimental channel. Braddock (1949) experimenting with *Platyopocilus maculatus* and Chapman (loc. cit.) with coho fry, both found that resident individuals held a distinct advantage over newly introduced fish in the establishment of a social hierarchy.

The results from this experiment, along with visual observations made in Robertson Creek, suggest that there may be an innate tendency on the part of some individual coho fry to migrate downstream while others show a tendency to move upstream. This basic pattern of behaviour appears to occur shortly after emergence and is not governed by size. Aggressive behaviour among individuals of both groups can cause a further displacement of subdominant individuals downstream. This latter displacement is accompanied by a segregation in size, the displaced individuals being smaller than those maintaining residence.

### Summary and Conclusions

The problem of determining the stream rearing requirements of coho juveniles is complex. It must eventually take into account the interrelationship between many factors. Such physical considerations as temperature, current velocities, space and cover must be evaluated. Basic behaviour patterns must be established and biotic factors such as food production, predation, competition and disease must be carefully studied.

The Robertson Creek rearing channels provide excellent opportunity for this research. Results of experiments to date on juvenile coho salmon production conducted at Robertson Creek, British Columbia, can be summarized as follows:

1. Shortly after emergence in the spring large numbers of coho fry moved both upstream and downstream from their place of emergence.
2. Fry that had moved upstream after emergence tended to remain in the artificial rearing channels to a greater extent than fry that had moved downstream.
3. The amount of downstream migration was controlled, at least in part, by the availability of low velocity water. Over twice as many fry remained in a pool-like situation as in a riffle-like situation. An intermediate number of fry remained when the depth-velocity situation was somewhere between pool and riffle.
4. The addition of shade reduced the initial holding capacity of one of the experimental rearing channels.



5. The addition of cover reduced the over-winter carrying capacity of one of the experimental rearing channels.
6. Coho fry in a riffle-like environment showed strong agonistic behaviour and territoriality.
7. Coho fry in a pool-like environment showed less agonistic behaviour and territoriality.
8. More age 1 coho smolts were produced in the pool-like environment.
9. More fish food was produced in the riffle-like environment.
10. The most coho smolt production occurred in a channel composed of one-half riffle and one-half pool. This was especially evident in terms of biomass of migrating smolts.

### Acknowledgments

I wish to thank Technicians Rob Elvidge and Iain McLean for their important and arduous role of data collecting and day to day maintenance of the experimental facilities. Construction changes and engineering details were carried out under the direction of Mr. K. H. Kupka, P.Eng. The support and direction of R. E. McLaren, Chief Biologist and D. MacKinnon, Senior Biologist, Resource Development Service, Department of Fisheries, Pacific Region, is gratefully acknowledged.

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